NASA
Technical
Paper
2803

March 1988

Investigation of the Misfueling of Reciprocating Piston Aircraft Engines

J. Holland Scott, Jr.

NASA

NASA Technical Paper 2803

1988

Investigation of the Misfueling of Reciprocating Piston Aircraft Engines

J. Holland Scott, Jr.

Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, Virginia

National Aeronautics and Space Administration

Scientific and Technical Information Division

TABLE OF CONTENTS

PRECEDING PAGE BLANK NOT FILMED

PREFACE

The investigation of the inadvertent misfueling of general aviation aircraft described in this report was conducted under certain policies adopted by the National Aeronautics and Space Administration (NASA) as a part of its charter. One of these policies states that the scientific technology developed as a result of the agency's operation shall be transferred to the user community for the benefit of mankind. Publication of this document represents the transfer of this information to the general aviation community and resolution of the agency's commitment. Reports from two private companies, who were employed to develop prototype instruments after a successful design concept was demonstrated, are included in this document. Both reports are published in their entirety to facilitate the readers comprehension of the project.

The Aircraft Misfueling Detection Project was managed by the Aeronautical Projects Section, Suborbital Projects and Operations Directorate; Goddard Space Flight Center/Wallops Flight Facility, Wallops Island, Virginia. Financial management was provided by the Chief Engineer's Office, NASA Headquarters, Washington, D.C. Support contractors for this investigation were the Aircraft Owners and Pilots Association (AOPA), Frederick, Maryland, and GOW-MAC Instrument Co., Bridgewater, New Jersey. Appreciation for their cooperation is gratefully acknowledged.

The author would like to thank all those who contributed to this effort, especially the task force steering committee for their conscientious guidance. Mr. Fred Quarles, an active AOPA member, deserves grateful recognition for his suggestion that jet fuel detection may be determined by use of the evaporation method. The Petroleum Testing Laboratory at the Norfolk Naval Supply Station, Norfolk, Virginia, tested our contamination samples to determine octane degradation, for which we are very appreciative.

Katherine Hooks, a most efficient Chemal,Inc. laboratory technician, spent many hours processing fuel samples and providing other valuable support. The enthusiasm she exhibited and her contributions to the project merit the special recognition of the author.

PRECEDING PAGE BLANK NOT FILMED

INVESTIGATION OF THE MISFUELING

OF

RECIPROCATING PISTON AIRCRAFT ENGINES

J. Holland Scott, Jr.
NASA Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, VA 23337

INTRODUCTION

The General Aviation Manufacturers Association (GAMA) and the American Petroleum Institute (API) convened a task force of industry and government representatives in Washington, D.C. during November, 1982. The group was charged with investigation of the rapidly increasing problem of inadvertent misfueling of general aviation aircraft. More specifically, the problem involved the introduction of jet fuel (either unadulterated or as a mixture with aviation gasoline) into a reciprocating piston aircraft engine. Designed solely for use of aviation gasoline (avgas), such engines are intolerant of jet fuel, often resulting in destruction of the engine and catastrophic aircraft crashes. The potential for injury, death, and equipment damage in these situations is unusually high.

This report contains the results of NASA's participation in the task force activities.

DESCRIPTION OF THE PROBLEM

From 1970 through 1981 there were 54 reported accidents related to improper fuel grade that occurred in the continental United States. Thirteen of these accounted for 34 fatalities and 43 serious injuries. Half involved privately owned aircraft, but 22 percent involved corporate/executive or air taxi operations. In four of the above accidents total pilot flight time in fixed-wing aircraft ranged from 4352 to 25871 hours. Of the four pilots, two had air transport ratings, one was a commercial flight instructor, and one was a private pilot. Aircraft misfueling accidents, as the profile indicates, can and do involve a wide cross section of pilots regardless of experience.

The task force of industry and government representatives, after reviewing these alarming statistics, organized a concerted effort to reduce the potential for misfueling general aviation aircraft. The result was promotion of innovative devices and methods such as fuel identification decals, banded fuel nozzles, fuel filler pipe restrictors, oversize jet fuel nozzles, standard refueling procedures, and educational/awareness training programs. NASA, currently engaged in preliminary work on the problem, elected to develop specific tests to identify contaminated fuel prior to its consumption in a reciprocating piston aircraft engine.

Typically, many accidents related to misfueling happen during take-off under maximum power as the reciprocating piston engine is exposed to high stress conditions and as damage to the engine occurs. As a result of consuming contaminated fuel there is seldom sufficient time or altitude after engine damage commences to take evasive action to avoid a crash, a factor that probably contributes to the high fatality rate associated with incidents of this type. There have also been incidents where aircraft were misfueled but fortunately the error was discovered in time to prevent mishap. Incidents of these types, for the most part, go unreported, therefore the misfueling problem is more widespread than statistics tend to imply.

Misfueling often results from carelessness or ignorance and quite often flightline personnel are involved. A typical example is the reciprocating piston engine DC-3 that crashed while departing a St. Louis airport after being misfueled. Failing to start an avgas refueler the flightline attendant mistakenly started a jet refueler and pumped jet fuel into the aircraft resulting in one fatality and one serious injury. A similar accident occurred at Salisbury, Maryland when an Aero Commander 500B crashed on take-off killing all five persons aboard. The flightline attendant had refueled with only a small amount of jet fuel, but enough to cause the aircraft to crash.

Jet fuel contamination of avgas can easily occur before the fuel reaches the flightline. Generally, refineries maintain high standards of quality control over their products and formerly, the major fuel processors delivered fuel directly to the flightline and, on occasion, to the waiting aircraft. This control of their product is now placed in the hands of transport companies that pick up the products at the refinery and transport them to local area distributors. These distributors then transport the fuel to the airport where it is placed in storage to be transported to the flightline in refuelers by flightline personnel. The potential for contamination of avgas exists at many points in the transportation process and increases with more frequent handling of the fuel.

The jet engine, unlike the reciprocating piston engine which requires avgas, operates on a less costly, more efficient, kerosene base fuel. With the advent of the jet engine, fixed-base operators (FBO's) who previously refueled aircraft exclusively with avgas are now dispensing both fuels simultaneously. Thus the potential for inadvertently mixing the two fuels is increasing with greater jet fuel usage. The jet fuel contaminant causes a highly destructive process known as "detonation" when the mixture is consumed in a reciprocating piston engine.

The effect of consuming jet fuel in a reciprocating piston engine is both rapid and destructive. During the compression stroke of a spark ignition engine the pressure, density, and temperature are increased. The mixture is ignited by an electrical spark after a proper delay time. The flame front created by ignition travels across the combustion chamber at a more or less orderly rate as pressure rises uniformly. Ahead of the flame front the unburned mixture is compressed by the rising pressure with a corresponding rise in temperature and density. Injection of jet fuel as a contaminant alters the ignition point of the unburned gas so that it ignites before the flame front arrives. The result is autoignition within the unburned gases in advance of the approaching flame front. The orderly process becomes uncontrolled and a violent pressure rise occurs. Energy is released at such a high rate that the walls of the chamber vibrate. This phenomena is known as detonation and is analogous to the more familiar "knocking" in an automotive engine. It can become so extreme as to cause catastrophic destruction of the combustion chamber with subsequent engine failure.

Contamination of avgas by jet fuel also results in a decreased octane rating when compared with pure avgas. Therefore, the degradation was used as a baseline with which the test data derived from this experimentation could be related. <u>It must be emphasized that this was not an attempt to evaluate the tolerance of a reciprocating piston engine for contaminated fuel.</u> The Petroleum Testing Laboratory at the Norfolk Naval Supply Station in Norfolk, Virginia, analyzed fuel samples to assist in evaluation of the extent of degradation at various contaminations. The Petroleum Testing Laboratory used a standard laboratory knock engine for these tests. It contains a single cylinder, overhead valves, a two-bowl carburetor, and a continuously variable compression ratio that may be changed at will during the operation. A synchronous generator, phased to a.c. power, maintains constant speed. The two carburetor float bowls can be raised or lowered to change the fuel/air ratio. A blended fuel of known octane number, composed of n-heptane (octane number = 0) and iso-octane (octane number = 100), is placed in one bowl and the contaminated sample is placed in the other. The engine is started on the standard fuel under highly controlled conditions (temperature, air intake, spark advance, etc.). The fuel/air ratio is adjusted until maximum knock is obtained. The engine is then adjusted to a standard compression ratio and locked into position. The standard fuel is then replaced with the contaminated fuel and its octane rating is obtained from the standard knock meter on the engine. Table #1 illustrates the data obtained from this operation.

TABLE #1 OCTANE LOSS FROM CONTAMINATION

FUEL	CONTAMINATION LEVEL				
	1%	2%	3%	4%	5%
JET-A	* 0.9	1.8	2.6	3.6	4.7
JP-4	0.6	1.2	2.2	2.7	3.3
JP-5	1.0	1.9	2.7	3.5	4.6

* OCTANE REDUCTION

Engine manufacturers generally allow approximately 10 to 12 percent change in fuel/air ratio as a detonation margin. If this detonation margin is applied to knock limited power curves it will be found to equate to an octane loss of 2 to 3 octane numbers. That is, a loss of 2 to 3 octane numbers will use up the design safety margin and theoretically subject the engine to possible damage from detonation. Data from Table #1 indicates that a loss of 2 octane numbers is reached slightly beyond 2% contamination of avgas by jet fuel. Therefore, a detection test must be capable of identifying any heavy hydrocarbon content in excess of that found in a mixture of 2% jet fuel contamination. This criteria becomes the sensitivity requirement of the evaporation test discussed in the following section.

TEST DESIGN PHILOSOPHY

The necessity of designing separate test instruments for each of two situations became quickly evident during the early stages of this investigation. Since contamination can occur at many points along the transportation route the FBO has a valid argument for an instrument with which to exercise good quality control over his fuel handling operation and assure delivery of an uncontaminated product to the aircraft. However, not all pilots obtain fuel from an FBO and the need exists for a pilot oriented test to be performed during pre-flight tests that will assure him that he has uncontaminated fuel for flight. The pilot's test, performed on the flightline, must be quickly and easily completed in an environment that is protected from varying flightline conditions. The FBO, however, operates in a less variable environment afforded by his hangar office. He also services a large number of pilots and these two factors justify more comprehensive testing and test equipment than those required by the pilot.

The philosophy described above led to the development of the Evaporation Test and the Gas Chromatograph Test for the pilot and the FBO, respectively. Prototype instruments were designed for the Evaporation Test by AOPA of Frederick, Maryland and for the Gas Chromatograph Test by GOW-MAC Instruments, Inc. of Bridgewater, New Jersey. The philosophy and data described in the following text were utilized in the design of these instruments. Reports from each of these companies are included in this document as ATTACHMENTs A(C-1) and B(D-1). NASA's intention is to record the results of this investigation so that the aircraft industry may benefit from its use to decrease the potential for misfueling general aviation aircraft.

Avgas and jet fuel are both composed of hydrocarbon compounds that are classified into four general types. These include paraffins, napthenes, aromatics, and olefins; and their molecular weights vary respectively with paraffins being the lightest and most mobile. Avgas is comprised primarily of smaller, lighter hydrocarbon molecules while those of jet fuel are larger and heavier. Thus, identification of the detonation potential of jet fuel contamination in avgas becomes a factor of identifying the relative amount of the heavier compounds present. Quantitative measurement is not necessary since pure avgas and contaminated avgas furnish unique characteristics that are easily identified by comparative analysis. In the case of the Evaporation Test, jet fuel contamination was found to retard the evaporation rate of avgas. The retardation exhibited a direct relationship to the amount of contamination present and it becomes an excellent measure of that contamination. The physical appearance of the evaporating fuel sample also takes on a unique characteristic that provides a qualitative test for contamination of avgas by jet fuel.

The Gas Chromatograph Test, similar in principle to the Evaporation Test, is a more comprehensive test requiring more sophisticated equipment but providing greater sensitivity. It utilizes the principle of preferential adsorption of hydrocarbon compounds by a selective medium. Comparative analysis of the resulting data may also be employed since pure avgas components provide entirely different adsorptive characteristics than those of avgas contaminated with jet fuel.

Other test methods such as refractometry, paper chromatography, spectrofluorimetry, digital photometry, etc. were investigated for possible use in this project. Each was eliminated in favor of evaporation (pilot's test) and gas chromatography (FBO's test) as a means of detecting jet fuel contamination of avgas. Most of the rejected methods were eliminated because of unreasonable equipment expense or increased test complexity.

Each of the two selected fuel contamination detection tests was subjected to intensive investigation in the chemistry laboratory at the Wallops Flight Facility. The result was construction of a data base from which test sensitivity, sample size, contamination level, and environmental effects could be determined. The remainder of this document describes the manner in which that data was obtained and the recommendations that resulted from its analysis.

EVAPORATION TEST

The first evaporation tests were performed using ordinary brown kraft paper as the evaporation medium. Its universal availability and low cost were attractive for use in an inexpensive evaporation kit designed for use by pilots on the flightline. However, inconsistent results were obtained since kraft paper contains large variations in composition. Laboratory filter paper, unlike kraft paper, is produced under precise composition specifications and good quality control and though more expensive, it produced excellent results. Its use in an evaporation kit projected a considerable increase in expense. Tests were also performed on a relatively inexpensive white adding machine paper. It proved to be a very efficient alternative to those evaporation media previously tested. Data results were quite similar to those derived from the use of laboratory filter paper and it is recommended for use in a low cost evaporation kit.

Environmental testing commenced after the paper evaporation medium was established. Excessive wind conditions were found to accelerate fuel evaporation, however, short term effects of temperature (0 to 40 deg C) and relative humidity (40 to 99%) were found to have a negligible effect. The use of a closed or protected container is recommended in

Attachment A (C-3) to eliminate the effects of wind and precipitation on the kit as it is used on the flightline.

The basic Evaporation Test for contaminated fuel consists of applying a measured fuel sample to the adding machine paper and observing its evaporation. Upon initial application the wet fuel appears as a visible spot on the paper. If the sample size is large, excess fuel may appear on the inner portion of the spot. If the fuel is uncontaminated, the spot will shrink evenly to very small dimensions before it completely disappears. In contrast, if the fuel is contaminated, the spot will not shrink as evaporation occurs. Instead it will evaporate evenly over the entire area until it is no longer visible.

The second observation is the time required to complete evaporation This is a measurable quantity and a more objective assessment of evaporation rate as a detection method. Assume that a pilot performs an evaporation test with a specific volume of an unknown sample. If the sample is pure avgas it will evaporate within a specific time. This time establishes the lower limit of an interval; the upper limit of which is the evaporation time of an equal volume of contaminated avgas. The interval, referred to as the "detection interval" is that time after initial application during which the paper must display no visible sign of unevaporated fuel if the sample is uncontaminated. Conversely, if the sample is contaminated, visible sign of unevaporated fuel will be displayed during the detection interval. It was necessary to establish the upper and lower limits for sample size and contamination levels by laboratory analysis. A sample size range of one (0.05 ml.) to five (0.25 ml.) drops and a contamination range of one to five percent were selected to provide evaporation test design data. Fifty samples were evaporated at each combination of sample size and contamination level over the selected ranges.

The acquired data indicates that evaporation of one-drop samples produced detection levels that were too brief to identify jet fuel contamination of avgas. Some of the larger samples required more than 20 minutes to completely evaporate where high contamination levels were involved. Obviously, a test of such length is not practical for flightline operations. Small volume samples with low contamination levels evaporated much more rapidly and appear to be more practical. Figure 1 describes a typical detection interval.

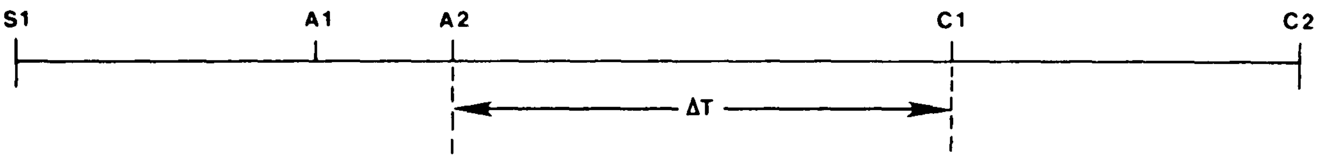


Figure 1. Typical Detection Interval

Where T = Detection Interval
$S1$ = Start of Evaporation
$A1A2$ = Evaporation Range for 50 Samples Avgas
$C1C2$ = Evaporation Range for 50 Samples Contaminated Avgas

If any unevaporated fuel is observed at any time during the detection interval the fuel sample must be considered to be contaminated.

Pure avgas exhibited a rapid evaporation rate and a sharply defined evaporation point. Thus the data (evaporation times) were tightly dispersed about the avgas distribution mean (Ta), forming a sharply peaked distribution curve as shown in Figure 2. In contrast, contaminated fuels evaporated less rapidly and evaporation points were more subtle and difficult to define, resulting in broader distribution about the mean (Tc) and a flatter distribution curve.

These data represent a normal Gaussian distribution and, as such, contain a probability of performance and a probability of non-performance, that when added, equals one. Therefore, extending the probability by using more than one standard deviation has the desired effect of increasing the probability of performance even though the detection interval is decreased. If the probability is extended to + or - five standard deviations (99.9999%) then the probability of non-performance becomes 0.000001% (1/1000000). Applying this logic (as shown in Figure 2) allows the selection of a time differential that is a detection interval (P5) with a reasonable risk of non-performance (failure to identify contaminated fuel) that is acceptable to the general aviation community. The following equation was derived to evaluate detection intervals:

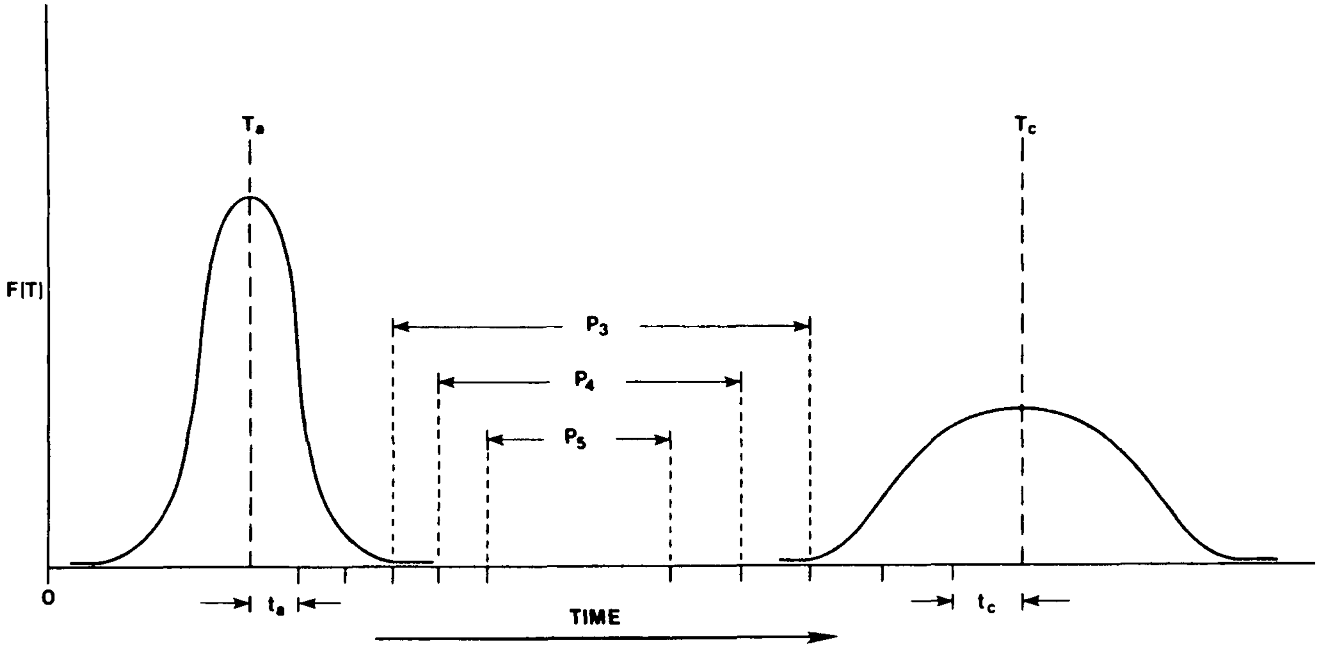


Figure 2. Evaporation Rate Distribution

$$T = [Tc - P(tc)] - [Ta + P(ta)]$$

Where:

- T = Detection Interval
- Ta = Avgas Distribution Mean
- Tc = Contaminated Avgas Distribution Mean
- ta = Avgas Standard Deviation
- tc = Contaminated Avgas Standard Deviation
- P = Desired Probability (number of standard deviations)

Detection intervals in Appendix A (A-1) were calculated by use of this equation and reflect the effects of varying sample size and contamination levels. Generally, the smaller sample sizes and lower contamination levels furnished shorter detection intervals. In fact, some of the samples evaporated so rapidly that negative numbers were generated indicating no available detection time. The length of time required to complete the entire test has been included (in parenthesis) since it is a prime consideration in selection of a suitable detection interval. If the detection interval is subtracted from the total test length, the result is the start time of the detection interval. Use of this data to design an evaporation test is predicated on the knowledge of two requirements: (1)desired sensitivity and (2)total test time. For example, if the user requires positive identification of all contamination in excess of 4% and a test length not to exceed five minutes in duration he is restricted to a sample size of either one or two drops. Any contamination of avgas in greater concentration than that selected from the data in Appendix A (A1-A2) will provide an indication of that contamination during the selected detection interval.

GAS CHROMATOGRAPHY TEST

Gas chromatography is an analytical technique that separates a compound into its basic components by preferential adsorption to a coated surface. Gas chromatographs are used to analyze a wide variety of compounds and many are designed primarily for laboratory use. Consequently, they are quite complex and costly. However, these instruments are easily redesigned for specific usage, producing a much simplified and less costly design. A typical example of a specific use gas chromatograph is an instrument utilized by arson investigators to identify accelerants used in fires of suspicious nature. Such an instrument, specifically designed as a misfueling detection device is recommended for use by the FBO to aid him in maintaining good quality control over his own refueling operations and to verify the pilot's Evaporation Test in the event contamination is suspected.

The basic components of a gas chromatograph include an oven, a column, a thermal conductivity detector, a signal conditioner, and an output recorder. The oven temperature may be manually or automatically varied, or it may be locked in isothermally which is adequate for misfueling detection. A gas chromatography column, a stainless steel tube (3.048m. by 0.3175m.), packed with specially coated porous particles (10% SP-2340 on 80/100 Chromosorb), is contained within the oven. The packing absorbs a limited range of hydrocarbon compounds including those of avgas and jet fuel.

Helium, the carrier gas, flows constantly through the column to the detector and after sufficient warm-up time the detector is automatically zero-calibrated. Then a carefully measured fuel sample is injected into the heated input port where it is immediately vaporized. The helium gas transports the vaporized sample through the column where its hydrocarbon components are adsorbed and desorbed at different rates. The lighter, more volatile components are desorbed first and consequently reach the detector before the heavier components. As each of the components passes through the detector it produces an electrical signal proportional to the amount of each component present in each sample. The signal is conditioned to drive a chart recorder that produces a pattern of peaks (chromatogram) each of which identifies a component of the sample. If test conditions such as sample size, oven temperature, and helium flow are held constant chromatogram repeatability is excellent. Thus it is a simple matter to compare an unknown sample with a pure avgas sample to ascertain if the jet fuel components are present.

As stated above, the output from a gas chromatograph is a pattern of peaks known as a chromatogram which is capable of representing each basic component of a complex hydrocarbon compound. Such a chromatogram is found in Appendix IV of Attachment B (D-52). It will be noted that the basic avgas components appear as a large flat-top peak. The chromatogram has been highly amplified to allow the small peaks that follow to be identified thus causing the flat-top or overamplification of the avgas component. The small following peaks indicate the presence of some of the basic components of jet fuel since even pure avgas contains them in minute quantities. The chromatogram obtained from one percent contamination demonstrates the same avgas peak but the jet fuel peaks are increased in amplitude, clearly identifying the increased contamination level. The size of the peaks is directly proportional to the contamination level and the time required to exit the column and produce a signal at the detector does not vary as long as all conditions are held constant. Thus, the peaks are easily identified as jet fuel components.

Chromatograms of known contaminated fuels are in effect "signatures" with which the signature of an unknown sample may be compared to determine the extent of jet fuel contamination. A gas chromatograph is capable of accurately detecting levels of jet fuel in avgas as low as 1%. Basic operation of the modified instrument is simple and results are highly repeatable. Overall; the reliability, brevity, sensitivity, and operational facility of the Gas Chromatograph Test combine to make it a feasible method of maintaining fuel integrity for the FBO"s operations. The method is also a very efficient back-up to confirm the Evaporation Test in the event the pilot of a recently refueled aircraft suspects contamination.

GOW-MAC Instruments Company under contract to NASA, was assigned the task of modifying an existing gas chromatograph to verify the conclusions of this investigation. The modified instrument produced excellent results, verifying the capability of identifying contamination levels of as low as one percent. It was also equipped with a small microcomputer that performed an analysis of the signal from the output and provided a simplified user oriented "go/no go" LED display. The complete report may be found in Attachment B(D-1).

CONCLUDING REMARKS

The detection methods described in this report have been researched and verified. This is the extent of the requirements of the Aircraft Misfueling Detection Project and this report represents the final documentation. However, in the interest of aviation safety, an additional observation must be reported.

In the course of this investigation many FBO's, pilots, and aircraft owners were interviewed, resulting in a genuine concern by most for fear of misfueling or being misfueled. However, in some cases, we encountered a cavalier approach to misfueling that leads to dangerous complacency. This was exemplified by some FBO's who were not interested in purchasing detection equipment because they "had never experienced a situation where any of their personnel misfueled an aircraft with jet fuel." Likewise, the question arose quite often as to whether pilots would take the time to use the Evaporation Test. Such attitudes are obviously dangerous in the aviation community where pilots and FBO's are responsible for the personal safety of others. The two tests described in this report have been proven to accomplish the detection of jet fuel contamination of avgas. They are, however, dependent on the attitude of the user. Commercialization of these products must be implemented by the aviation industry if they are to be utilized effectively by the aviation community. Since there are no regulations on the use of such devices it is incumbent on the industry to research the marketing of these products to maximize their use in the interest of aviation safety.

APPENDIX A

EVAPORATION TEST

DATA SUMMARY

1 DROP SAMPLE SIZE:

CONTAMINATION LEVEL	SENSITIVITY 1X MIN	2X MIN	3X MIN	4X MIN	5X MIN
1%	* 0.14	0.01	-0.11	-0.24	-0.36
	**(1.01)	(0.92)	(0.84)	(0.75)	(0.67)
2%	1.14	0.77	0.40	0.02	-0.35
	(2.01)	(1.68)	(1.34)	(1.01)	(0.68)
3%	1.88	1.47	1.06	0.64	0.23
	(2.75)	(2.38)	(2.01)	(1.63)	(1.26)
4%	3.67	3.24	2.81	2.38	1.94
	(4.54)	(4.15)	(3.76)	(3.36)	(2.97)
5%	4.83	4.04	3.26	2.47	1.68
	(5.70)	(4.95)	(4.21)	(3.46)	(2.71)

2 DROP SAMPLE SIZE:

1%	0.32	0.12	-0.09	-0.29	-0.50
	(1.43)	(1.29)	(1.14)	(0.99)	(0.85)
2%	3.02	2.24	1.46	0.68	-0.09
	(4.13)	(3.41)	(2.69)	(1.97)	(1.25)
3%	3.76	3.10	2.44	1.78	1.12
	(4.87)	(4.27)	(3.67)	(3.07)	(2.47)
4%	5.71	5.04	4.37	3.69	3.02
	(6.82)	(6.21)	(5.59)	(4.98)	(4.37)
5%	7.89	7.03	6.17	5.32	4.46
	(9.00)	(8.20)	(7.40)	(6.60)	(5.80)

* DETECTION INTERVAL LENGTH (MINUTES)
** MAXIMUM TEST LENGTH (MINUTES)

X=STANDARD DEVIATION
(NEGATIVE VALUES INDICATE NO DETECTION TIME AVAILABLE)

3 DROP SAMPLE SIZE:

1%	0.60 (1.93)	0.08 (1.48)	-0.44 (1.03)	-0.96 (0.58)	-1.48 (0.13)
2%	4.00 (5.32)	3.33 (4.73)	2.67 (4.14)	2.00 (3.54)	1.34 (2.95)
3%	6.43 (7.75)	5.81 (7.20)	5.18 (6.65)	4.56 (6.10)	3.94 (5.55)
4%	8.88 (10.21)	7.65 (9.04)	6.41 (7.88)	5.18 (6.72)	3.94 (5.55)
5%	10.44 (11.76)	9.07 (10.47)	7.70 (9.17)	6.33 (7.88)	4.97 (6.58)

4 DROP SAMPLE SIZE:

1%	1.37 (3.01)	0.55 (2.29)	-0.27 (1.57)	-1.08 (0.85)	-1.90 (0.14)
2%	4.49 (6.13)	3.81 (5.55)	3.14 (4.97)	2.46 (4.40)	1.78 (3.82)
3%	8.32 (9.96)	7.37 (9.11)	6.41 (8.25)	5.45 (7.39)	4.50 (6.53)
4%	15.32 (16.96)	13.95 (15.69)	12.59 (14.43)	11.22 (13.16)	9.86 (11.89)
5%	17.89 (19.53)	16.61 (18.35)	15.33 (17.17)	14.05 (15.99)	12.77 (14.81)

5 DROP SAMPLE SIZE:

1%	2.30 (4.19)	1.47 (3.44)	0.64 (2.69)	-0.19 (1.95)	-1.02 (1.20)
2%	5.23 (7.12)	4.57 (6.54)	3.90 (5.95)	3.23 (5.37)	2.57 (4.78)
3%	10.45 (12.34)	9.35 (11.32)	8.25 (10.30)	7.15 (9.29)	6.06 (8.27)
4%	16.47 (18.36)	15.41 (17.38)	14.35 (16.40)	13.29 (15.42)	12.23 (14.44)
5%	25.16 (27.06)	23.94 (25.92)	22.72 (24.77)	21.50 (23.63)	20.28 (22.49)

APPENDIX B

References

1. AVCO Lycoming, AVCO Detonation Analyzers-Description, 1980 Williamsport Division, Williamsport, Pennsylvania.

2. AVCO Lycoming, AVCO Lycoming Requirements to Conduct an In-Flight Detonation Survey, 1980, Williamsport Division, Williamsport , Pennsylvania.

3. National Institute for Petroleum and Energy Research, Inc., Aviation Turbine Fuels, 1984, Bartlesville, Oklahoma.

4. National Transportation Safety Board, Briefs of Accidents, U.S. General Aviation, Washington, D.C. (Computer Generated on Demand)

5. AOPA Air Safety Foundation, 1981, Detecting Jet Fuel Contamination of Avgas, Safety Bulletin No. 1, Frederick, Maryland.

6. Society of Automotive Engineers, Inc., Handbook of Aviation Fuel Properties, 1983, Warrendale, Pennsylvania.

7. Obert, Edward F., 1910-, Internal Combustion Engines, 1968, Scranton International Textbook Co.

8. National Transportation Safety Board, Accident File Contents, Factual Report, 1978 IAD 78-F-A056, "Aviation Accident/Incident", Washington, D.C.

9. National Transportation Safety Board, Accident File Contents, Factual Report, 1984, MKC 84-M-A060, "Aviation Accident/Incident", Washington, D.C.

10. Banks, Herbert W. R., National Transportation Safety Board Initial Briefing to the General Aviation Manufacturer's Association, "Improper Fuel Grades.", 1982, National Transportation Safety Board, Field Investigation Division, Washington, D.C.

APPENDIX C

DEVELOPMENT OF A TEST KIT TO DETECT JET FUEL CONTAMINATION OF AVGAS

RUSSELL S. LAWTON
VICE PRESIDENT, OPERATIONS
AOPA AIR SAFETY FOUNDATION
421 AVIATION WAY
FREDERICK,MARYLAND

BACKGROUND

A test procedure to identify aviation fuel contaminated with jet fuel was developed and tested under the Aircraft Misfueling Detection Project. Data was collected to quality operational tests that may be used by pilots to detect contaminated aviation gasoline (avgas) prior to take-off. Repeated use of a test kit by pilots is highly dependent on the utility and attractiveness of the final configuration for the kit.

The AOPA Air Safety Foundation was asked by NASA/Goddard Space Flight Center/Wallops Flight Facility to design and test the final configuration of this kit among pilots, aircraft owners and fixed-base operators (FBO's). The Air Safety Foundation was well suited for this purpose since it conducts training programs attended by more than 10,000 pilots and aircraft owners annually.

With respect to the design and evaluation of the test kit, the Air Safety Foundation was asked to:

(1) Review available accident reports to determine the operational modes that could affect the design of the test kit.
(2) Conduct a survey of pilots, aircraft owners and FBO's to obtain information pertinent to test kit design. In addition, FBO's were also to be surveyed on the feasibility and practically of using a gas chromatograph detection unit.
(3) Describe the design of a prototype contamination detection kit.
(4) Make recommendations for additional testing of the

design parameters if necessary.
(5) Provide design drawings for an operational test kit and instructions for its use.

METHODOLOGY

Accident/Incident Review

Aircraft misfueling accidents and incidents from 1964 to 1983 were reviewed to develop a profile of the typical misfueling situation. These accidents are classified as "Fuel Grade - Improper," and include those accidents/incidents where the incorrect type of fuel was used instead of the fuel for which the engine was originally certified, e.g., auto fuel, jet fuel, wrong grade, etc. The following data bases were queried in order to retrieve this information:
*Federal Aviation Administration (FAA) - Accident/Incident Data System (AIDS)
*International Civil Aviation Organization (ICAO) - Accident Data Reports (ADREPS)
*National Aeronautics and Space Administration (NASA) - Aviation Safety Reporting System (ASRS)
*National Transportation Safety Board (NTSB) - Briefs of Accidents for U.S. General Aviation

The accident/incident reports from the five data bases were compared in order to eliminate duplicate reports. Seventy-seven reports were found under the classification "Fuel Grade - Improper." There were no reported accidents/incidents where single engine aircraft certified to use aviation gasoline were misfueled with jet fuel. The single engine aircraft accidents reviewed were caused due to water contamination and/or the improper use of auto fuel.

The aircraft most often misfueled with jet fuel were twin engine aircraft belonging to a manufacturer's product line utilizing both piston and turbine engines, e.g., Aero Commander and Cessna 400 series. Other twin engine aircraft misfueled with jet fuel were the result of improperly trained flight line service personnel who assumed that the aircraft should be serviced with jet fuel instead of avgas.

The most reliable method of detecting jet fuel contamination of avgas when utilizing the evaporation test is by obtaining a fuel sample from the aircraft fuel tank filler port where the jet fuel may be introduced. The fuel tank filler ports on many of the aircraft involved in misfueling accidents are difficult to access by pilots during normal preflight inspection without the use of a ladder. It was recommended that NASA conduct a test to determine how quickly the fuel in an aircraft tank could be contaminated with jet fuel when it was introduced at the filler neck and combined with avgas.

A test was conducted at the Wallops Flight Facility to determine the time required for a two percent by volume sample of jet fuel to completely mix with a container of avgas. Although the two fuels mixed almost instantly within the container, more time would be required for the contaminated fuel to settle into an aircraft fuel strainer and sump system.

Many aircraft utilize multiple fuel tanks and intricate fuel line systems. Therefore, the evaporation test method is most reliable when a fuel sample is obtained from the fuel tank filler port.

Detection Kit Development

Demonstrations of the evaporation test were conducted by Air Safety Foundation staff at various training programs throughout the United States. Approximately 600 pilots and aircraft owners observed the test utilizing laboratory filter paper and avgas samples composed of two percent and five percent levels of jet fuel contamination. Everyone observing the test was impressed with its simplicity and ease of use.

Those in attendance were asked if they would purchase a kit if the price were under ten dollars. Many stated that they would <u>not</u> purchase the kit if the cost was more than ten dollars.

Considering the feedback received from these people, it is determined that the test kit should be constructed from readily available materials so that it can be produced and sold commercially for less than ten dollars. Other factors that need to be considered in the design of the test kit are:

* Durability and ease of portability.
* Ability to withstand temperature extremes.
* A sufficient quantity of test paper to conduct repeated tests.
* A method of shielding the test paper from wind since the rate of evaporation is critical in the detection of jet fuel.

The project team believed that most pilots and aircraft owners would not go to a location where laboratory filter paper is sold in order to obtain replacement paper for sampling. Other paper types were evaluated which might be more readily available. A good substitute was found by using plain white calculator paper which was <u>not</u> treated with any type of pressure sensitive material. This type of paper is both readily available and inexpensive, thereby, being more conducive to frequent use and replacement. Plain white calculator paper made from 12-lb. lightweight bond was evaluated by the NASA Goddard Space Flight Center/Wallops Flight Facility and determined to be of consistent quality for repeated evaporation tests.

A box capable of holding a 2-1/4" wide roll of calculator paper was fabricated from 1/8" clear acrylic (Figure 1). The paper roll is fed through a tension device which assures a flat area on the paper for conducting the test. A 1-1/2" diameter opening on the tension device is used to place the fuel sample on the paper. The tension device is set 3/4" down from the top of the box for wind protection. A feed slot on the box side allows the used paper to be removed, torn off, and replaced by a clean sample. Once the paper supply is depleted, it can be replaced by turning the box upside down and sliding out the used paper roll. A holder for the eye dropper and attachment line was mounted on the box lid.

Once the prototype test kit was fabricated and refined, demonstrations were conducted at Air Safety Foundation training programs. The pilots and aircraft owners in attendance observed a demonstration of the test kits and were given an opportunity to conduct the test individually. Comments concerning the simplicity and ease of using the test kit were extremely positive. Most who participated and/or observed the demonstration stated they would purchase the kit if it sold in the

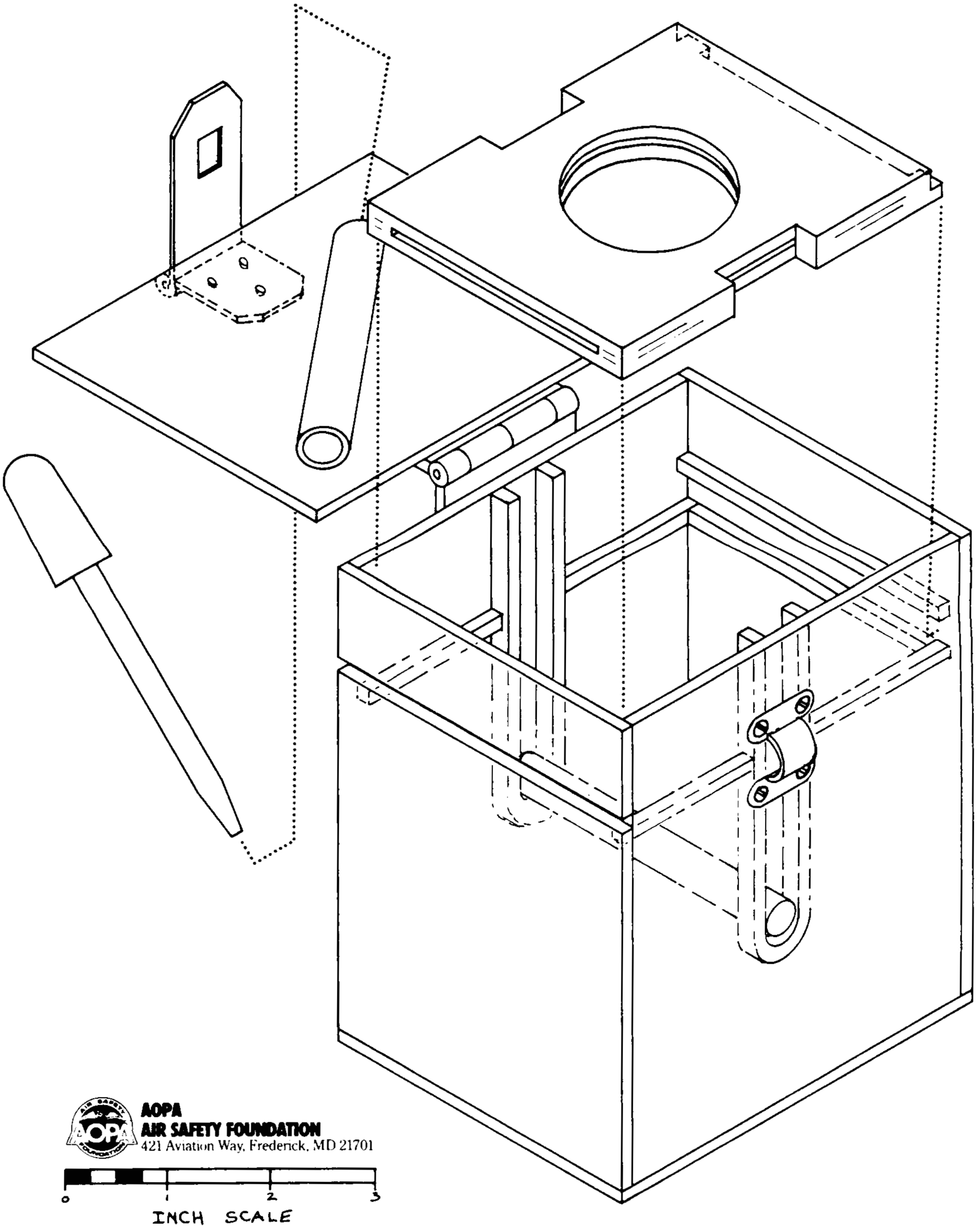


Figure 1.Detection Kit Design

$10-$15 price range.

Demonstrations of the prototype test kit were also conducted at ten fixed base operators (FBO's) in the eastern U.S. The FBO staffs observing the demonstrations were also impressed that jet fuel contamination could be detected with this simple method. These same FBO's were also queried concerning the possibility of using a gas chromatograph as a positive test once jet fuel contamination was suspected. Although the FBO personnel were generally in favor of using a more positive indication of jet fuel contamination, they balked at purchasing a $1500 - $2000 instrument which could only be used for this one test procedure.

These same FBO's expressed reticence at purchasing this equipment since they had never experienced a situation where any of their personnel misfueled an aircraft with jet fuel. The FBO's expressed interest in viewing a demonstration of the gas chromatograph, however a demonstration unit was not available when the survey was conducted.

Design Parameters

The prototype test kit developed by the Air Safety Foundation which was described previously and detailed in Figure 1 appears to meet the objectives in the Statement of Work. The test kit is small enough to be carried in the typical pilot's flight case. The essential kit components (paper roll and eye dropper) are easy to replace and inexpensive. Most importantly, the test kit can repeatedly detect a jet fuel contamination level of two percent by volume.

The test kit should be constructed from acrylic material of at least 1/8" thickness to withstand normal wear and tear as well as the range of temperatures encountered in aviation operations. Prototype test kits were constructed of 1/16" plastics, but these were not of adequate durability.

The white calculator paper worked as well as the laboratory filter paper in detecting jet fuel contamination of avgas. A roll of calculator paper costs approximately one dollar and is normally 200 feet long. Anyone conducting the test need not be concerned with the expense of the paper, and hopefully, will conduct as many tests as necessary to be confident that no jet fuel contamination exists.

The eye dropper used to obtain the fuel samples is stored on the lid of the test kit. A nylon line three feet in length attaches the eye dropper to the test kit. The nylon line allows the individual to retrieve the eye dropper in the event it is dropped into the fuel tank while obtaining a fuel sample for the test.

Recommendations

The Air Safety Foundation does not believe that any further testing and/or development of the prototype jet fuel contamination detection kit is required. The evaporation test method of detecting jet fuel contamination of avgas has been thoroughly tested and documented by NASA. The prototype test kit developed by the Air Safety Foundation with the assistance of the NASA Goddard Space Flight Center/Wallops Flight Facility meets the objectives for detecting jet fuel contamination on a repeated basis.

Instructions for Use of Test Kit

The recommended construction for the test kit is detailed in Figure 2. The following procedure should be followed when using the kit during preflight inspection:

(1) Remove the eye dropper from holder and unwind nylon line to full length (approximately three feet).

(2) Using the eye dropper, obtain a fuel sample from the fuel tank opening.

(3) Place two drops of the fuel on the flat surface of the paper contained in the 1-1/2" circular opening in the test kit. A spot about the size of a quarter should be formed.

(4) Observe the outside of the spot as it dries. Pure avgas will evaporate from the outside moving inward, leaving the outer margin indistinct. After approximately two minutes, pure avgas will disappear completely, leaving no signs of a spot, having completely disappeared.

(5) Jet fuel contaminated avgas will show a distinct perimeter on the paper, and fade only after several minutes. The jet fuel will often leave a filmy substance on the paper which is easily observed when held up to a light source.

(6) Remove the used paper sample from the side of the box and tear off. If contamination is suspected, repeat the procedure using a sample of the suspect fuel. Remove the test paper and save. Obtain a sample of pure avgas and place on clean test paper. Compare the evaporation rates for the two samples. If the pure avgas sample evaporates more quickly , the suspect sample may be contaminated.

AOPA
AIR SAFETY FOUNDATION
421 Aviation Way, Frederick, MD 21701

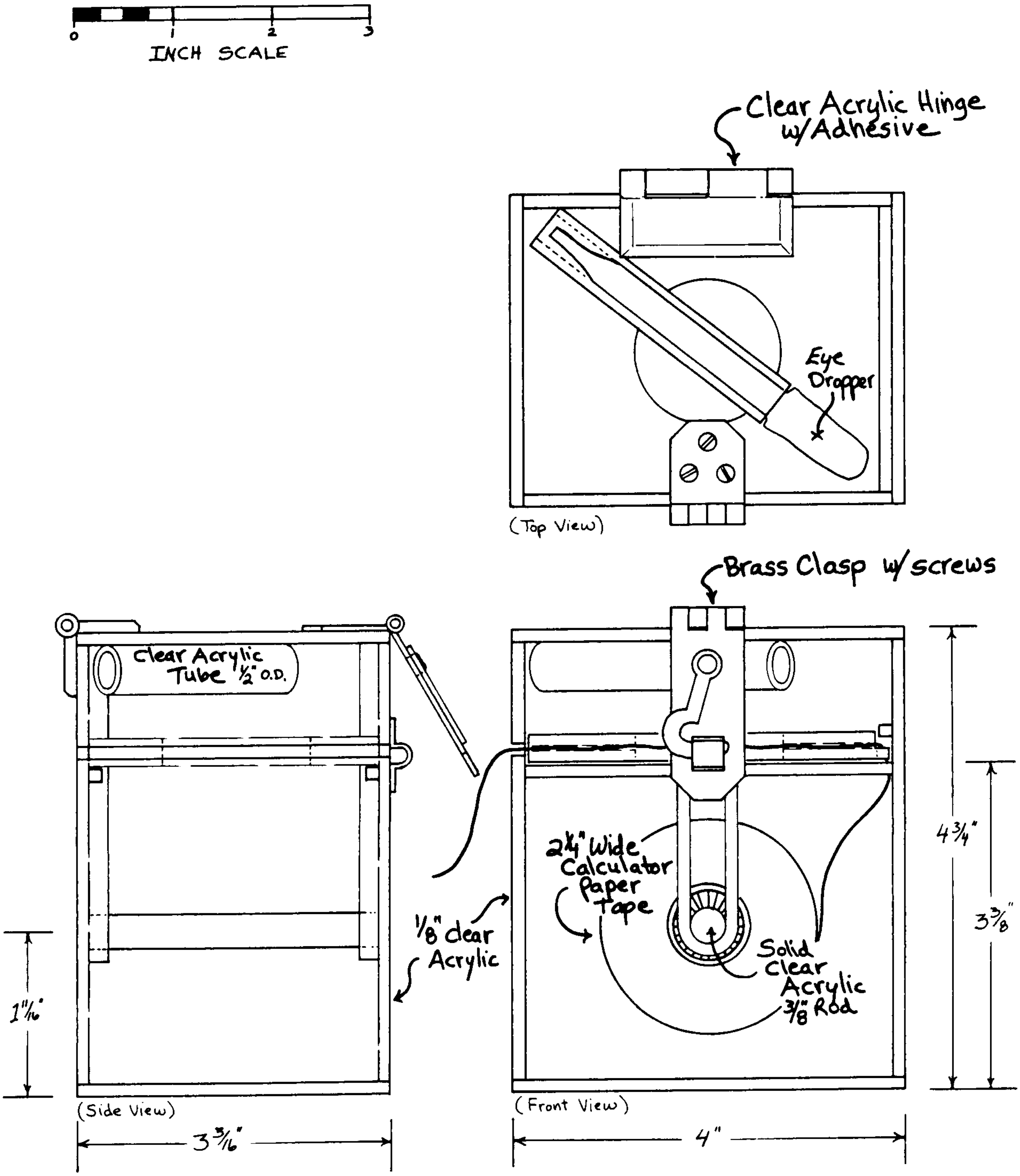


Figure 2. Details of Design Specifications

REFERENCES

Accident Data Reports, International Civil Aviation Organization, Montreal, Quebec, Canada.

Briefs of Accidents, U.S. General Aviation, National Transportation Safety Board, Washington, D.C.

"Contamination of Aviation Gasoline with Heavier Fuels." American Society of Testing and Materials.

"Detecting Jet Fuel Contamination of Avgas," Safety Bulletin #1. AOPA Air Safety Foundation, Frederick, Maryland.

"General Aviation Accidents Involving Misfueling as a Cause or Factor." Federal Aviation Administration, Safety Analysis Division, Washington, D.C.

"Substitution of Jet Fuel for Avgas," Search Request No. 808. Aviation Safety Reporting System, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California.

APPENDIX D

MODIFICATION TO A GAS CHROMATOGRAPH

TO DETECT JET FUEL CONTAMINATION OF AVIATION GASOLINE

(STATEMENT OF WORK # 824-477381620)

FOR: NASA, GODDARD SPACE FLIGHT CENTER
WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

Prepared By:
GOW-MAC Instrument Co.
X.F. Gonzalez, Consultant

ABSTRACT

A thermal conductivity gas chromatograph in conjunction with a Signal Processing Module capable of detecting one percent jet fuel contamination peak has been successfully tested. The Signal Processor accepts the gas chromatograph signal and utilizes an algorithm implemented with a single chip microcomputer to perform the analysis of the aviation fuel. An LED display and a single START/STOP switch provides simplified user oriented "go/no go" analysis. The use of a microcomputer allows for adjustment of retention time zones and peak value threshold. The software has been written to allow upgrading to detect other fuel contamination.

INTRODUCTION

The detection of jet fuel contamination of aviation gasoline has been successfully demonstrated in the chemistry laboratory at GSFC/WFF. Tests conducted under the Aircraft Misfueling Detection Project have detected concentrations as low as 1 percent by use of a laboratory type gas chromatograph. However the interpretation of the resulting output limits the flightline use of the instrument.

This project adapts the chromatograph output for use by the fixed base operator (airport manager). The instrument modification designed is a Signal Processing Module that provides a visual indication of the fuel sample analysis. The instrument system has been successfully tested at the GOW-MAC Instrument Company over ranges of 50% to 1% jet fuel contaminations as well as 0% jet fuel contamination.

OVERALL SYSTEM CONFIGURATION

The system consists of a dual column gas chromatograph (GOW-MAC Model 69-5590), a carrier gas cylinder, and Signal Processor Module. Figure 1 illustrates the basic system. The columns on the gas chromatograph have been selected to separate the aviation fuel and the jet fuel components under specific conditions. The aviation fuel sample to be tested is injected into the injection port where it vaporizes and is carried by the carrier gas. The vaporized sample of aviation fuel and any jet fuel contamination are separated in the column. The separate components are passed through the thermal conductivity detector which senses the relative thermal conductivity of the component gases. An electrical signal, proportional to the thermal conductivity of each component, is generated as it passes through a resistance bridge detector.

The Signal Processor Module is a specially designed unit that utilizes the detectors electrical signal to determine if the aviation fuel peak occurs at the correct time and if there is any jet fuel contamination present.

SIGNAL PROCESSOR MODULE (HARDWARE DESCRIPTION)

A typical chromatograph of 1% contaminate is shown in Figure 2. The main peak due to aviation fuel has a retention time of 1 minute and a peak that exceeds 1 millivolt. The main peak of the jet fuel contamination has a retention time of approximately 2 minutes and a peak in the order of 0.035 millivolts. The system used to detect the contaminate is shown in Figure 3. The system consists of a single chip microprocessor (Intel 8751), a 12 bit Digital to Analog Converter (DAC), highly specialized analog operational amplifiers and visual display via drivers. A microprocessor was chosen to provide future flexibility to detect other contaminates that may be present in the aviation fuel. Additionally, retention time zones and signal threshold constants can be adjusted by changing constants in Read Only Memory(ROM).

The DAC in conjunction with the microprocessor is configured into a tracking analog to digital converter (ADC). The ADC loop is controlled by a comparator capable of sensing 10 microvolt differences around zero. This sensitive comparator had to be made from a high gain amplifier (OP06). The output of OP06 is used to saturate a comparator (LF311). The digital signal out of the LF311 comparator goes into a microprocessor input port and is used to indicate the signal polarity (within 10 microvolts).

The gas chromatograph signal from the bridge circuit is fed into a balanced summing amplifier (OP07). The balanced DAC output is injected into the amplifier so as to null out the bridge voltage. The output of the comparator indicates to the processor the direction that the DAC must be driven in order to null the detector signal. The microprocessor updates the DAC at a 0.25 millisecond rate in an attempt to null the amplifier. The DAC will easily track the low frequency (10hz bandwidth) gas chromatography signals and high frequency noise will average zero.

The microprocessor controls the eight display LEDs. A group of five LEDs are used to assist the operator in zeroing the bridge. A push button is used to activate the timing cycle to measure the sample retention time. The push button can also be used to abort the timing cycle. The timing cycle is shown in Figure 4. The RUN LED is used to indicate the status of the timing cycle. When the timing cycle is active the RUN LED is on. When the timing cycle is completed the analysis of the sample is finished and the RUN LED blinks. To reset the timing cycle the push button is pressed and the RUN LED goes off. Two more LEDs indicate a pass or failed condition after the analysis is completed. Refer to the schematic in Appendix I for a more detailed circuit.

SIGNAL PROCESSOR MODULE (SOFTWARE DESCRIPTION)

Refer to Figure 5 for a flow chart description of the software driver. A description of each procedure follows:

1. TIC COUNT:
   Is a real time interrupt procedure used to keep track of time. It also passes tokens to the main program to activate procedures in the main program.
2. DAC UPDATE:
   Test the "signal polarity" input port. It determines the sense of the detector signal and outputs a 12 bit digital signal to the DAC in opposition to the sensed signal in order to null the detector's bridge signal. An internal count of the DAC value (DAC-COUNTER) is maintained and updated during this procedure.
3. SWITCH:
   This routine will sample the START/STOP switch input port. Toggles the

"START" flag used internally to start a run or to abort a run.

4. TIME:
   Maintains the internal flags and initializes internal flags.
5. LITE:
   This routine maintains the output display. The zero adjustment routines help the operator zero the bridge. When the bridge signal is zero the green LED will be turned on. Two yellow LEDs (one positive and the other negative off zero conditions) indicate a slightly off zero condition. Two red LEDs (one positive and the other negative off zero condition) indicate that the operator must adjust the bridge zero before starting. If either of the two RED LEDs are blinking it indicates that the zero is out of the DAC range and must be zeroed before starting. The RUN LED is:
   A. Off if START flag has not been activated.
   B. On if START flag has been activated.
   C. Blinks if the run is completed.
      The Pass and Fail LEDS indicate the result of the analysis at the completion of the run.
6. ZONE:
   When the START flag is activated a RUN-COUNTER keeps track of the time. This counter is used to maintain 5 zones used to measure retention time.
   A. ZONE 0 — STOPPED
   B. ZONE 1 — 0 to 30 seconds
   C. ZONE 2 — 30 to 90 seconds (avgas fuel peak expected)
   D. ZONE 3 — 90 to 150 seconds (contamination peak, if any, expected)
   E. Zone 4 > 150 seconds (run completed)
7. ANALYSIS;
   The analysis procedure is used to detect:
   A. The aviation fuel peak during the Zone 2 interval.
   B. Any contamination peaks during Zone 3 interval.

The detection of the aviation fuel is done by comparing the DAC-COUNTER (value) during Zone 2. If the DAC-COUNTER exceeds a given constant then the aviation fuel peak has been sensed.

This constant is an absolute value and is chosen very near the maximum DAC value. The detection of the contamination is performed by integrating, during the time Zone 3, the detector signal. If this integral exceeds a predetermined constant (selected at 1% contamination for this unit) then a FAIL-ed condition is flagged.

The flow chart indicates the execution sequence of the described procedures. A more precise documentation is supplied in Appendix II which provides the PLM source and the subsequent assembler code that has been generated.

SIGNAL PROCESSOR OPERATION

An operator would proceed as follows:

1. Set up the G.C. to the given operating conditions (see Appendix III) and wait 30 minutes for the G.C. temperature to stabilize.
2. Zero the detector by ob-

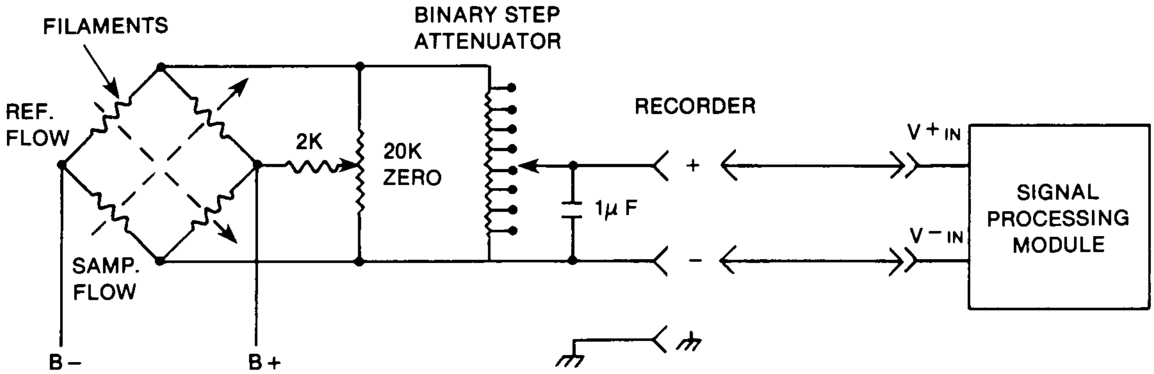
serving the zeroing LEDs. Adjust the zero until in the green or either yellow LED is on.

3. Check the RUN, PASS, and FAIL LEDs. These LEDs should be off. If not, depress the START/STOP switch to abort the run and prepare for a new start.
4. Obtain a sample of the fuel mixture to be tested and inject it into the injection port.
5. Immediately press the START/STOP button to start the analysis. The yellow RUN LED will come on.
6. A the end of the run (150 seconds) the yellow LED will blink indicating the end of the run. The PASS or the FAIL LED will be activated as the result of the analysis.

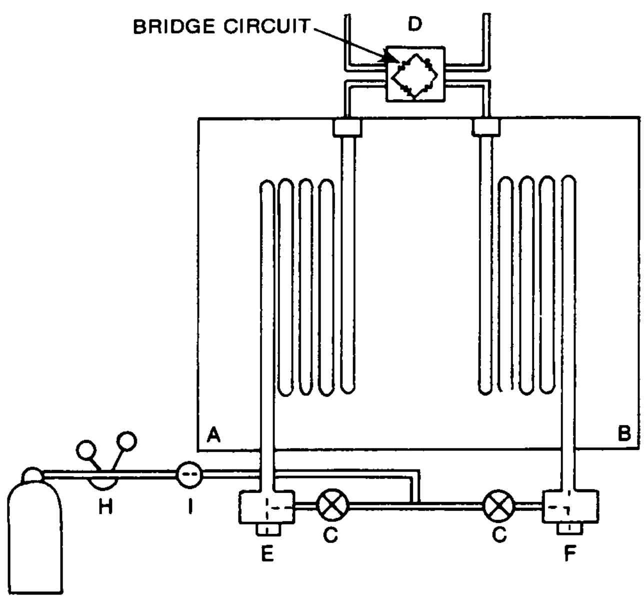
TESTING

Testing of the Signal Processing Module was conducted over several days. Aviation fuel samples with jet fuel contamination from 1% to 50% were tested successfully. Also tested successfully were the pure samples of aviation fuel. Recorder output of the tests are provided in Appendix IV. From these tests it appears that a GOW-MAC Model 550 gas chromatograph in conjunction with the modification is capable of detecting low level contaminations.

FIGURE 1A. DETECTOR ELECTRICAL OUTPUT



BRIDGE CIRCUIT (DETECTOR)



A. COLUMN "A"
B. COLUMN "B"
C. METERING VALVES (2) "A" &"B"
D. DECTECTOR BLOCK
E. INJECTION PORT FOR COLUMN "A"
F. INJECTION PORT FOR COLUMN "B"
G. HELIUM TANK
H. PRESSURE REDUCTION VALVE
I. PRESSURE SWITCH

FIGURE 1B. G.C. SYSTEM

Figure 1. Basic System

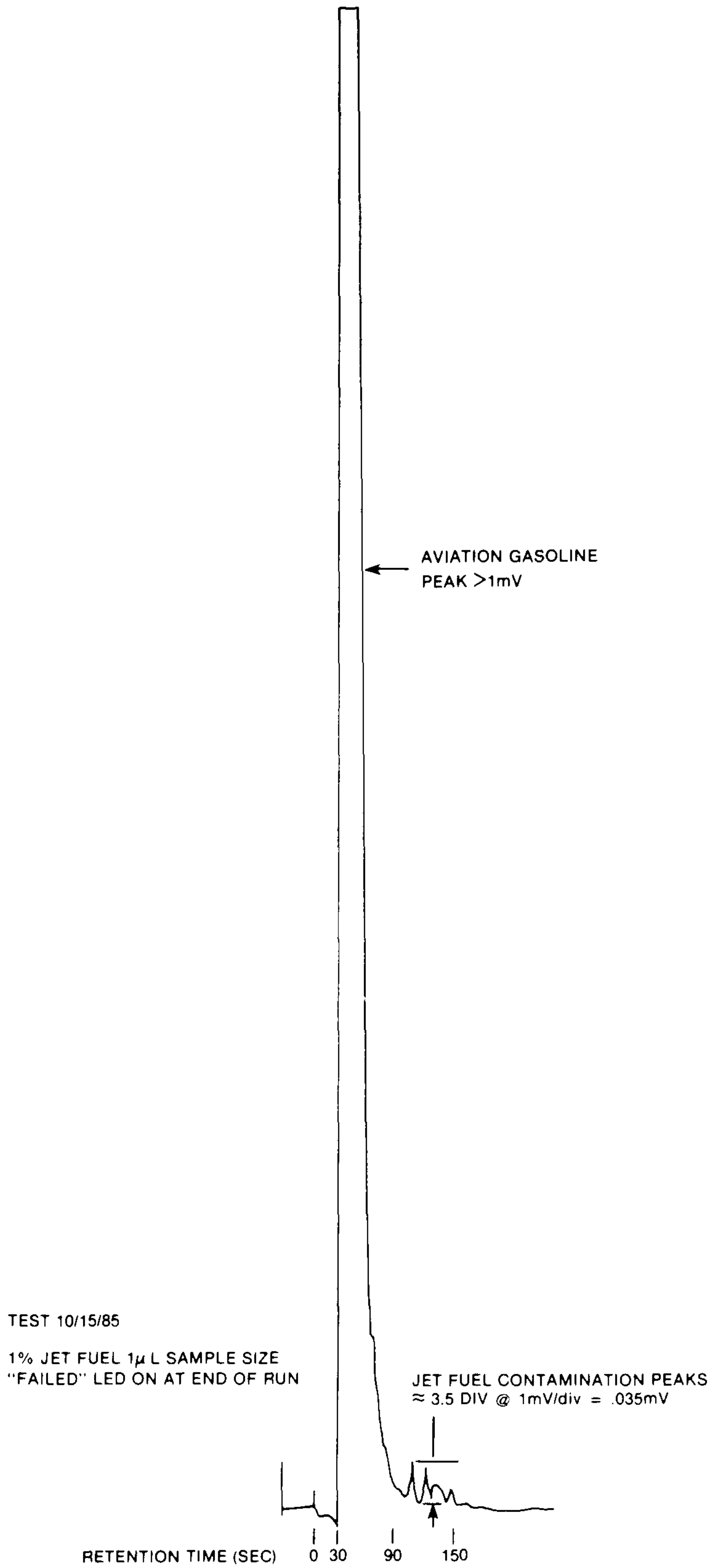


Figure 2. 1% Jet Fuel Contamination of Aviation Gasoline Chromatography Profile

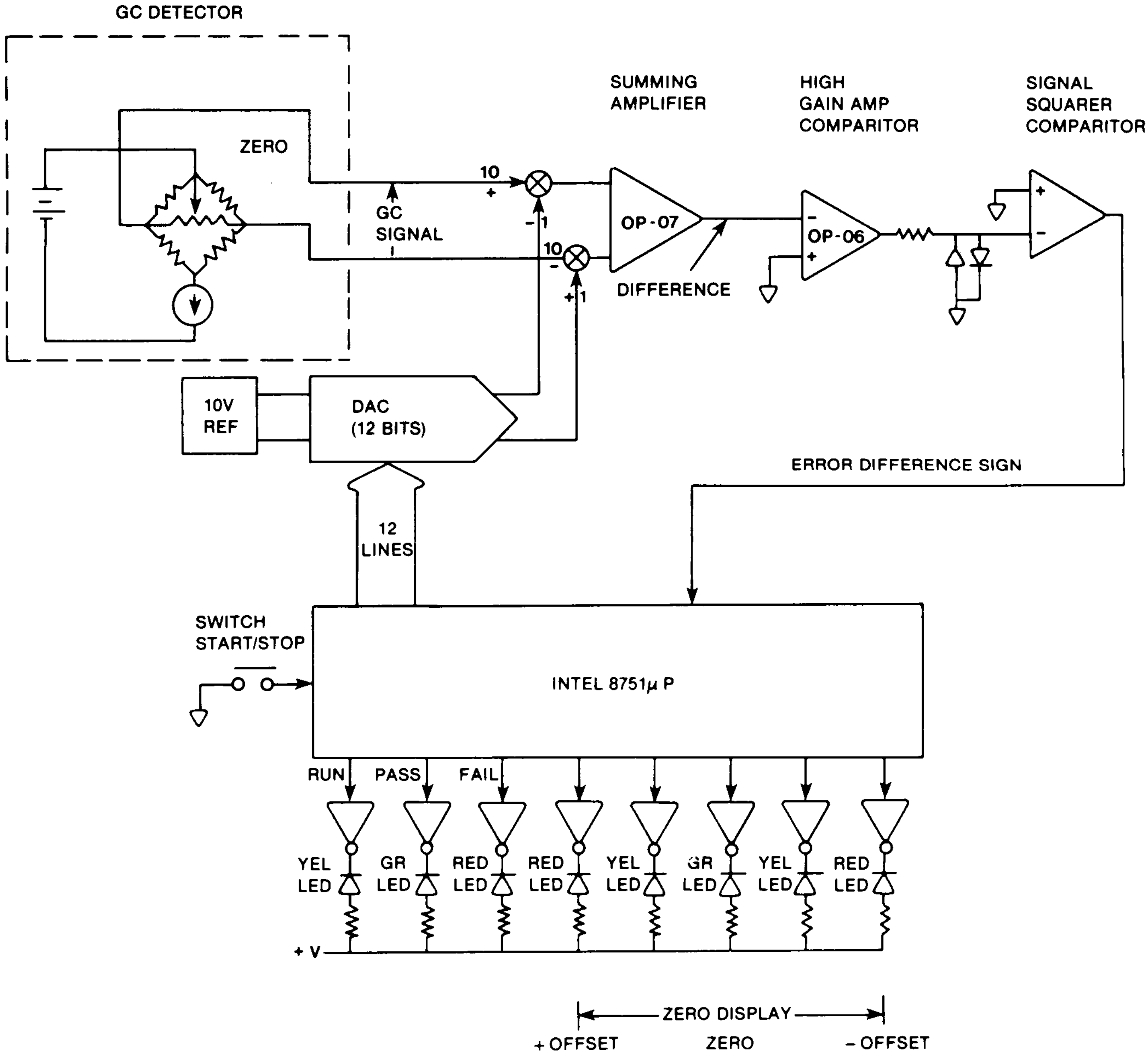


Figure 3. Aviation Fuel Contamination Signal Processor

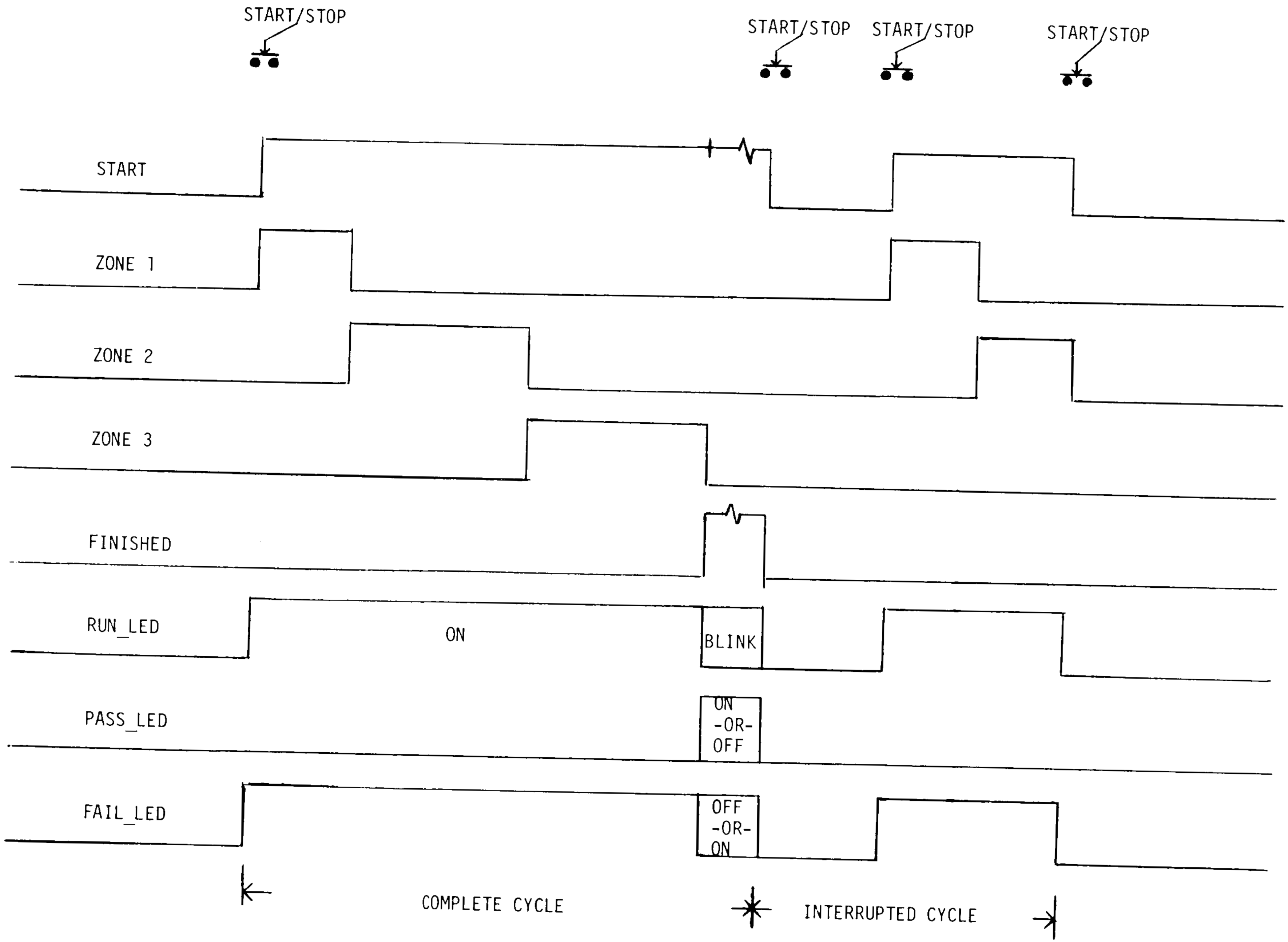


Figure 4. Timing Cycle

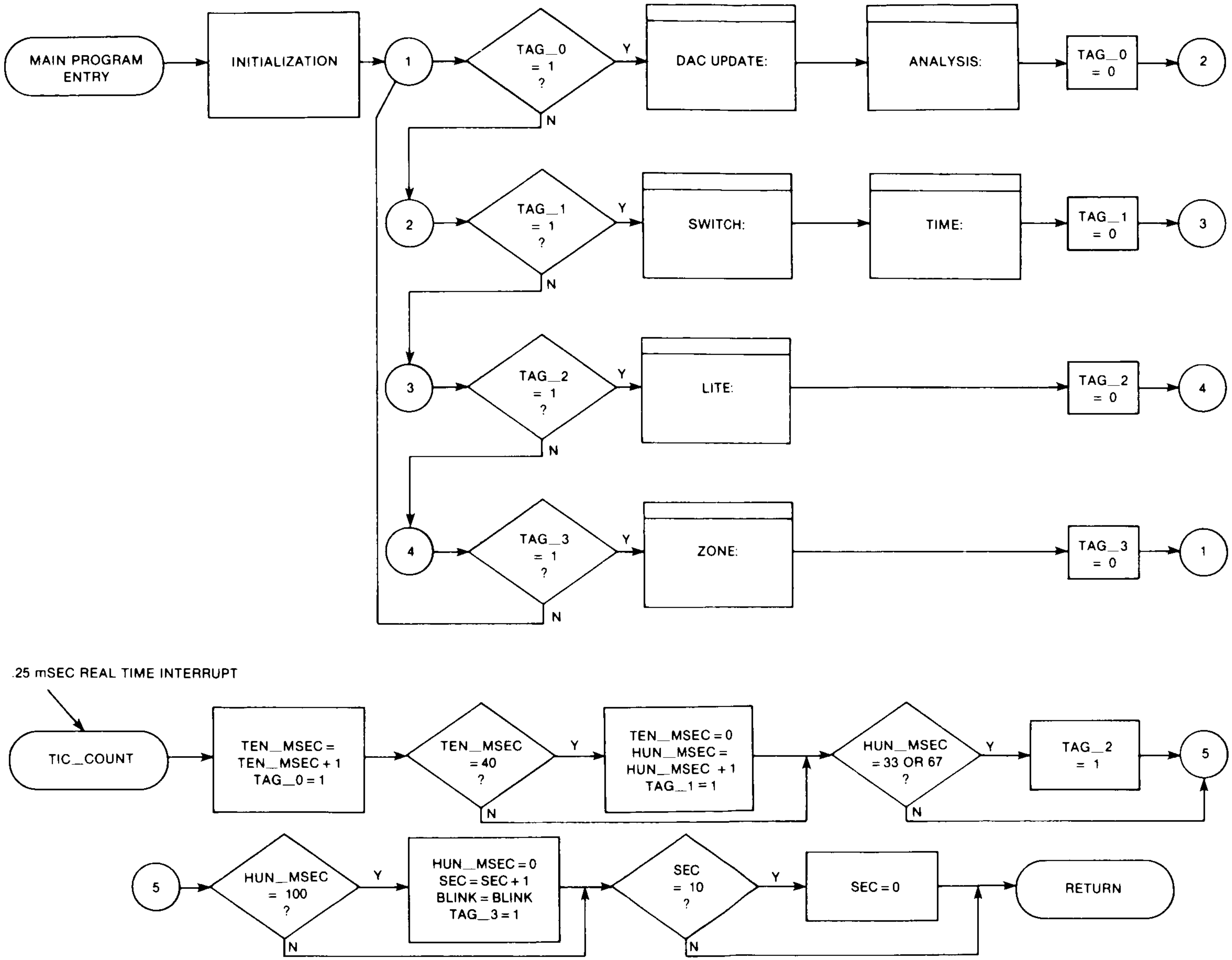
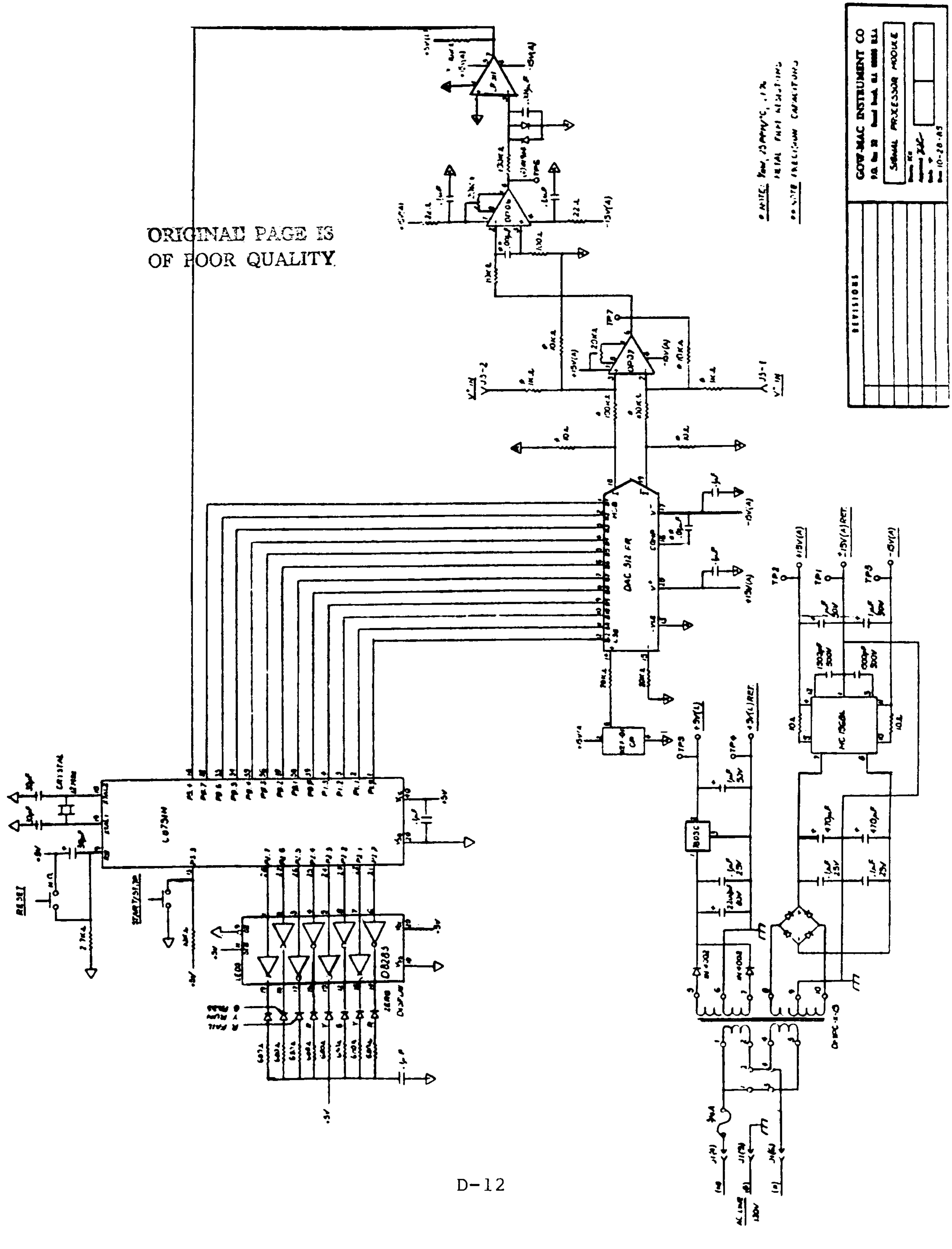


Figure 5. Program Flow

APPENDIX I

SIGNAL PROCESSOR SCHEMATIC

ORIGINAL PAGE IS
OF POOR QUALITY



APPENDIX II

SOFTWARE:

1. SOURCE PROGRAM & ASSEMBLY LEVEL PROGRAM
2. RELOCATOR & LINKER

```
ISIS-II PL/M-51 V1.1
COMPILER INVOKED BY: PLM51 NASOO.PLM DATE(9/15/85) DB OJ SB CO XREF


        /*****************************************************/
        /*                                                   */
        /*     NASA AVIATION FUEL CONTAMINATION SOFTWARE     */
        /*        BY: X. F. GONZALEZ                         */
        /*****************************************************/

1     1    NASA00: DO;          /*DECLARATION I/O REGISTERS FOR B051*/
2     1    DECLARE DCL LITERALLY 'DECLARE';
3     1    DCL PORT_0           BYTE AT(80H) REGISTER;
4     1    DCL SP               BYTE AT(81H) REGISTER;
5     1    DCL TCON             BYTE AT(88H) REGISTER;
6     1    DCL TMOD             BYTE AT(89H) REGISTER;
7     1    DCL SCON             BYTE AT(98H) REGISTER;
8     1    DCL IE               BYTE AT(0A8H) REGISTER;
9     1    DCL IP               BYTE AT(0B8H) REGISTER;
10    1    DCL PORT_1_BIT_0     BIT  AT(90H) REGISTER;
11    1    DCL PORT_1_BIT_1     BIT  AT(91H) REGISTER;
12    1    DCL PORT_1_BIT_2     BIT  AT(92H) REGISTER;
13    1    DCL PORT_1_BIT_3     BIT  AT(93H) REGISTER;
14    1    DCL HI_RED_LED       BIT  AT(0A0H)REGISTER;  /*P2.0*/
15    1    DCL HI_YEL_LED       BIT  AT(0A1H)REGISTER;  /*P2.1*/
16    1    DCL ZERO_GRN_LED     BIT  AT(0A2H)REGISTER;  /*P2.2*/
17    1    DCL LO_YEL_LED       BIT  AT(0A3H)REGISTER;  /*P2.3*/
18    1    DCL LO_RED_LED       BIT  AT(0A4H)REGISTER;  /*P2.4*/
19    1    DCL FAIL_LED         BIT  AT(0A5H)REGISTER;  /*P2.5*/
20    1    DCL PASS_LED         BIT  AT(0A6H)REGISTER;  /*P2.6*/
21    1    DCL RUN_LED          BIT  AT(0A7H)REGISTER;  /*P2.7*/
22    1    DCL EA               BIT  AT(0AFH)REGISTER;  /*ENABLE INTERRUPTS*/
23    1    DCL START_STOP_SW    BIT  AT(0B3H)REGISTER;  /*P3.3*/
24    1    DCL DAC_COMP         BIT  AT(0B4H)REGISTER;  /*P3.4*/
25    1    DCL DAC_COUNTER WORD;
26    1    DCL PEAK_COUNTER WORD;
27    1    DCL RUN_COUNTER WORD;
28    1    DCL TEMPER_WORD WORD;
29    1    DCL DAC_MAX_COUNT      WORD CONSTANT (0FFFH);
30    1    DCL PEAK_1             WORD CONSTANT (0FFFFH);
31    1    DCL PEAK_2             WORD CONSTANT (0EFFH);
32    1    DCL PEAK_3             WORD CONSTANT (00FFH);
33    1    DCL WINDOW_1           WORD CONSTANT (0700H);
34    1    DCL WINDOW_2           WORD CONSTANT (07F0H);
35    1    DCL WINDOW_3           WORD CONSTANT (080FH);
36    1    DCL WINDOW_4           WORD CONSTANT (08FFH);
37    1    DCL WINDOW_5           WORD CONSTANT (0FFFH);
38    1    DCL TIME_1             WORD CONSTANT (001EH);
39    1    DCL TIME_2             WORD CONSTANT (005AH);
40    1    DCL TIME_3             WORD CONSTANT (0096H);
41    1    DCL TIME_4             WORD CONSTANT (00C8H);
```

```
42    1    DCL TEN_MSEC     BYTE;
43    1    DCL HUND_MSEC    BYTE;
44    1    DCL SEC          BYTE;
45    1    DCL WINDOW       BYTE;
46    1    DCL ZONE_I       BYTE;

47    1    DCL UP_DNNOT_FLAG    BIT;
48    1    DCL TAG_0_INTR3      BIT;
49    1    DCL TAG_1_INTR3      BIT;
50    1    DCL TAG_2_INTR3      BIT;
51    1    DCL TAG_3_INTR3      BIT;
52    1    DCL BLINK            BIT;
53    1    DCL START            BIT;
54    1    DCL START_N          BIT;
55    1    DCL START_P          BIT;
56    1    DCL RUN              BIT;
57    1    DCL FINISH           BIT;
58    1    DCL ZONE_1           BIT;
59    1    DCL ZONE_2           BIT;
60    1    DCL ZONE_3           BIT;
61    1    DCL ZONE_4           BIT;
62    1    DCL FAIL_ZONE_1      BIT;
63    1    DCL PASS_ZONE_2      BIT;
64    1    DCL FAIL_ZONE_3      BIT;

              /*STRUCTURE TO OVERLAY BYTE ONTO BITS*/
65    1    DCL TEMPOR_BIT STRUCTURE ((B0,B1,B2,B3,B4,B5,B6,B7) BIT);
66    1    DCL TEMPOR_BIT_OVR BYTE AT ( .TEMPOR_BIT );

              $EJECT
67    2    TIC_COUNT:  PROCEDURE  INTERRUPT 3 USING 0;
                  /*USE 12 M HZ CLOCK TO OBTAIN .25 M SEC PER INTERRUPT */
68    2             TEN_MSEC=TEN_MSEC +1;
69    2             TAG_0_INTR3=1;
70    2             IF TEN_MSEC = 40 THEN
71    3             DO;
72    3               TEN_MSEC = 0;
73    3               HUND_MSEC = HUND_MSEC + 1;
74    3               TAG_1_INTR3=1;
75    3               IF (HUND_MSEC=33) OR (HUND_MSEC=67) THEN
                                             TAG_2_INTR3=1;
77    3               IF HUND_MSEC =100 THEN
78    4               DO;
79    4                   HUND_MSEC = 0;
80    4                   SEC = SEC + 1;
81    4                   TAG_3_INTR3=1;
82    4                   BLINK = NOT BLINK;
83    4                   IF SEC = 10 THEN SEC = 0;
85    4               END;
86    3           END;
87    1    END TIC_COUNT;
```

```
          $EJECT

88   2    DAC_UPDATE: PROCEDURE;

89   2        UP_DNNOT_FLAG = DAC_COMP;
90   2        IF UP_DNNOT_FLAG = 1 THEN
91   3        DO;
92   3            IF DAC_COUNTER >= DAC_MAX_COUNT THEN
93   3            DAC_COUNTER = DAC_MAX_COUNT;
94   3            ELSE DAC_COUNTER = DAC_COUNTER + 1;
95   3        END;
96   2        ELSE
              DO;
97   3            IF DAC_COUNTER = 0000H THEN
98   3            DAC_COUNTER = 0000H;
99   3            ELSE DAC_COUNTER = DAC_COUNTER - 1;
100  3        END;

              /*OUTPUT TO DAC*/
101  3        DO;
              /*OUTPUT MS BYTE TO DAC*/
102  3        TEMPOR_WORD = SHL (DAC_COUNTER,4);
103  3        PORT_0 = HIGH ( TEMPOR_WORD );
              /*OUTPUT LS BITS TO DAC*/
104  3        TEMPOR_BIT_OVR = LOW ( TEMPOR_WORD);
105  3        PORT_1_BIT_3 = TEMPOR_BIT.B7;
106  3        PORT_1_BIT_2 = TEMPOR_BIT.B6;
107  3        PORT_1_BIT_1 = TEMPOR_BIT.B5;
108  3        PORT_1_BIT_0 = TEMPOR_BIT.B4;
109  3        END;

110  1    END DAC_UPDATE;


111  2    ANALYSIS: PROCEDURE;
          /*THIS PROCEDURE PERFORMS THE ANALYSIS WITHIN EACH DESIGNATED
                                                          TIME ZONE*/

112  3            DO CASE ZONE_I;

113  3            ; /*ZONE 0; AWAITING START*/

114  4            DO; /*ZONE 1; NO PEAKS EXPECTED WITHIN ZONE*/
115  4             IF ZONE_1=0 THEN
116  5                DO;/*ZONE 1 INITIALIZATION*/
117  5                    ZONE_1 = 1;
118  5                END;
119  4             IF DAC_COUNTER > PEAK_1 THEN FAIL_ZONE_1 =1;
121  4            END;/*ZONE 1*/

122  4            DO;/*ZONE 2; MAIN PEAK MUST BE WITHIN ZONE*/
123  4             IF ZONE_2=0 THEN
124  5                DO;/*ZONE 2 INITIALIZATION*/
125  5                        ZONE_1=0;
```

```
126   5                    ZONE_2=1;
127   5                END;
128   4             IF DAC_COUNTER > PEAK_2 THEN PASS_ZONE_2=1;
130   4             END;/*ZONE 2*/
131   4             DO;/*ZONE 3; NO PEAKS EXPECTED WITHIN ZONE*/
132   4              IF ZONE_3=0 THEN
133   5                 DO;/*ZONE 3 INITIALIZATION*/
134   5                    ZONE_2=0;
135   5                    ZONE_3=1;
136   5                    PEAK_COUNTER=0000H;
137   5                 END;
                    /*MAINTAIN PEAK COUNTER*/
138   4             IF UP_DNNOT_FLAG = 1 THEN
139   5                DO;
140   5                IF PEAK_COUNTER < 0FFFFH THEN
141   5                PEAK_COUNTER = PEAK_COUNTER + 1;
142   5                END;
143   4             ELSE
                       DO;
144   5                IF PEAK_COUNTER > 0000H THEN
145   5                PEAK_COUNTER = PEAK_COUNTER - 1;
146   5                END;
147   4             IF PEAK_COUNTER > PEAK_3 THEN FAIL_ZONE_3 =1;
149   4            END;/*ZONE 3*/

150   4            DO;/*ZONE 4; STOP*/
151   4             IF ZONE_4=0 THEN
152   5                DO;/*ZONE 4 INITIALIZATION*/
153   5                ZONE_3=0;
154   5                ZONE_4=1;
155   5                END;
156   4            END;/*ZONE 4*/
157   3        END;/*DO CASE*/
158   1    END ANALYSIS;

159   2    SWITCH: PROCEDURE;

               /*THIS ROUTINE SAMPLES THE START_STOP_SW FOR CLOSURE.
                 THE START FLAG IS TOGGLED ON A LOW TO HIGH TRANSITION OF
                 THE SWITCH. DEBOUNCE IS PROVIDED BY CALLING THIS ROUTINE
                 AT 10 M SEC INTERVALS.*/

160   2    START_N=START_STOP_SW;
161   2    IF START_N=1 AND START_P=0 THEN START=NOT START; /*TOGGLE
                                                             START*/
163   2    START_P=START_N;     /*SAVE NEW SWITCH VALUE*/
164   1    END SWITCH;

165   2    TIME: PROCEDURE;
           /*THIS ROUTINE MAINTAINS THE TIMING FLAGS USED TO CONTROL
             THE RUNNING OF THE PROGRAM*/

166   2            IF START=0 THEN
167   3               DO;
```

```
168  3                RUN=0;
169  3                FINISH=0;
170  3                ZONE_1=0;
171  3                ZONE_2=0;
172  3                ZONE_3=0;
173  3                ZONE_4=0;
174  3                ZONE_I=0;
175  3            END;

176  2        IF (START=1) AND (RUN=0) AND (FINISH=0) THEN
177  3            DO;
178  3                FAIL_ZONE_1 = 0;
179  3                PASS_ZONE_2 = 0;
180  3                FAIL_ZONE_3 = 0;
181  3                RUN_COUNTER = 0000H;
182  3                RUN = 1;
183  3            END;
184  2      IF (START=1) AND (RUN=1) AND (ZONE_4=1) THEN
185  3          DO; /*FINISH*/
186  3              FINISH = 1;
187  3              RUN = 0;
188  3          END;
189  1    END TIME;

190  2    LITE: PROCEDURE;

       /*THIS ROUTINE MAINTAINS THE LED OUTPUT DISPLAY. THE FIRST
         PORTION IS USED TO HELP ZERO THE BRIDGE. WHEN THE BRIDGE IS
         ZERO THE GREEN LED WILL BE ON. TWO MORE BANDS (YELLOW, RED)
         ARE USED TO INDICATE THE MAGNITUDE AND DIRECTION (HI, LO)
         OF THE OFFSET FROM ZERO. TO START THE RUN THE GREEN LED
         MUST BE ON INDICATING THAT THE BRIDGE HAS BEEN ZEROED. THE
         OTHER PORTION OF THE ROUTINE MAINTAINS THE RUN, FAIL, AND
         PASS LED'S*/

191  2    WINDOW = 6;
192  2    IF DAC_COUNTER=0    THEN WINDOW=WINDOW-1;
194  2    IF DAC_COUNTER < WINDOW_1 THEN WINDOW=WINDOW-1;
196  2    IF DAC_COUNTER < WINDOW_2 THEN WINDOW=WINDOW-1;
198  2    IF DAC_COUNTER < WINDOW_3 THEN WINDOW=WINDOW-1;
200  2    IF DAC_COUNTER < WINDOW_4 THEN WINDOW=WINDOW-1;
202  2    IF DAC_COUNTER < WINDOW_5 THEN WINDOW=WINDOW-1;
204  2    IF DAC_COUNTER = 0FFFH    THEN WINDOW=WINDOW;
206  3    DO CASE WINDOW;
207  4        DO; /*CASE 0- VALUE AT MINIMUM*/
208  4            LO_RED_LED=BLINK;  /*BLINK LOW RED LED*/
209  4            LO_YEL_LED=0;
210  4            ZERO_GRN_LED=0;
211  4            HI_YEL_LED=0;
212  4            HI_RED_LED=0;
213  4        END;
214  4        DO;  /*CASE 1- VALUE BETWEEN MINIMUM AND WINDOW_1*/
215  4            LO_RED_LED=1;   /*LOW RED LED ON*/
216  4            LO_YEL_LED=0;
```

```
217  4              ZERO_GRN_LED=0;
218  4              HI_YEL_LED=0;
219  4              HI_RED_LED=0;
220  4          END;
221  4          DO;  /*CASE 2- VALUE BETWEEN WINDOW_1 AND WINDOW_2*/
222  4              LO_RED_LED=0;
223  4              LO_YEL_LED=1;  /*LOW YELLOW LED ON*/
224  4              ZERO_GRN_LED=0;
225  4              HI_YEL_LED=0;
226  4              HI_RED_LED=0;
227  4          END;
228  4          DO;  /*CASE 3- VALUE BETWEEN WINDOW_2 AND WINDOW_3*/
229  4              LO_RED_LED=0;
230  4              LO_YEL_LED=0;
231  4              ZERO_GRN_LED=1;   /*WITHIN ZERO LIMITS*/
232  4              HI_YEL_LED=0;
233  4              HI_RED_LED=0;
234  4          END;
235  4          DO;  /*CASE 4- VALUE BETWEEN WINDOW_3 AND WINDOW_4*/;
236  4              LO_RED_LED=0;
237  4              LO_YEL_LED=0;
238  4              ZERO_GRN_LED=0;
239  4              HI_YEL_LED=1;   /*HI YELLOW LED ON*/
240  4              HI_RED_LED=0;
241  4          END;
242  4          DO;  /*CASE 5- VALUE BETWEEN WINDOW_4 AND WINDOW_5*/
243  4              LO_RED_LED=0;
244  4              LO_YEL_LED=0;
245  4              ZERO_GRN_LED=0;
246  4              HI_YEL_LED=0;
247  4              HI_RED_LED=1;        /*HI RED LED ON*/
248  4          END;
249  4          DO;  /*CASE 6- VALUE AT MAXIMUM*/
250  4              LO_RED_LED=0;
251  4              LO_YEL_LED=0;
252  4              ZERO_GRN_LED=0;
253  4              HI_YEL_LED=0;
254  4              HI_RED_LED=BLINK;    /*BLINK HI RED LED*/
255  4          END;
256  3      END; /*DO CASE*/

            /* RUN LED CONTROL*/
257  2      IF START=0 THEN RUN_LED=0;
259  2      IF (RUN=1) AND (START=1) THEN RUN_LED=1;
261  2      IF (FINISH=1) AND (START=1) THEN RUN_LED=BLINK;

            /*FAIL LED CONTROL*/
263  2      IF START=0 THEN FAIL_LED=0;
265  2      IF(START=1) AND (FINISH=0) THEN
266  2          FAIL_LED=FAIL_ZONE_1 OR FAIL_ZONE_3;
267  2      IF FINISH=1 THEN
268  2          FAIL_LED=FAIL_ZONE_1 OR FAIL_ZONE_3 OR NOT
                                PASS_ZONE_2;
```

```
                /* PASS LED CONTROL*/
269  2          IF START=0 THEN PASS_LED=0;
271  2          IF (START=1) AND (FINISH=0) THEN
272  2              PASS_LED=PASS_ZONE_2;
273  2          IF FINISH=1 THEN
274  2              PASS_LED=NOT FAIL_LED;
275  1      END LITE;

    $EJECT

276  2      ZONE: PROCEDURE;
            /*THIS PROCEDURE MAINTAINS THE RUN COUNTER AND ESTABLISHES
            A TIME ZONE WHICH IS USED BY THE ANALYSIS PROCEDURE.*/

277  2          IF RUN=1 THEN
278  3              DO;
279  3                  IF RUN_COUNTER < TIME_4 THEN ZONE_I=4;
281  3                  IF RUN_COUNTER < TIME_3 THEN ZONE_I=3;
283  3                  IF RUN_COUNTER < TIME_2 THEN ZONE_I=2;
285  3                  IF RUN_COUNTER < TIME_1 THEN ZONE_I=1;
287  3                  RUN_COUNTER=RUN_COUNTER+1;
288  3              END;
289  1      END ZONE;

    $EJECT

    /***********************************************/

    /********  RESET ENTRY  **************/

                /*INITIALIZATION*/

290  1      SP=6FH;   /*SET UP STACK POINTER*/
291  1      TMOD=00010011B;  /*SET UP TIMER/COUNTER MODE REGISTER*/
292  1      TCON=01000000B;  /*SET UP TIMER/COUNTER CONTROL/STATUS
                                            REGISTER*/
293  1      SCON=00000000B;  /*SET UP SERIAL PORT CONTROL/STATUS
                                           REGISTER*/
294  1      IP=00011111B;    /SET UP INTERRUPT PRIORITY REGISTER*/
295  1      IE=00001000B;    /SET UP INTERRUPT ENABLE REGISTER*/
296  1      EA=1;     /*ENABLE INTERRUPTS*/

297  1      START=0;  /*INITIALIZE RUNNING PROGRAM*/
298  1      ZONE_I=0;
299  1      DAC_COUNTER = 0000H;

    /*******************************************/
                   /*MAIN PROGRAM*/

300  2      DO WHILE 1;      /*DO BLOCK FOREVER*/
301  3          DO WHILE TAG_0_INTR3=1;  /*THIS DO LOOP IS DONE ONCE
                         EVERY .25 MSEC*/
```

```
302   3              CALL DAC_UPDATE;
303   3              CALL ANALYSIS;
304   3              TAG_O_INTR3=0;
305   3             END;
306   3             DO WHILE TAG_1_INTR3=1;  /*THIS DO LOOP IS DONE ONCE
                                                EVERY 10 MSEC*/
307   3              CALL SWITCH;
308   3              CALL TIME;
309   3              TAG_1_INTR3=0;
310   3             END;
311   3             DO WHILE TAG_2_INTR3=1;  /*THIS DO LOOP IS DONE ONCE
                                               EVERY 330 MSEC*/
312   3              CALL LITE;
313   3              TAG_2_INTR3=0;
314   3             END;
315   3             DO WHILE TAG_3_INTR3=1;  /*THIS DO LOOP IS DONE ONCE
                                               EVERY SECOND*/
316   3              CALL ZONE;
317   3              TAG_3_INTR3=0;
318   3             END;
319   2         END;         /*END WHILE 1 LOOP*/
320   1        END NASA00;    /*END MODULE NASA00*/
                    ; PROCEDURE NASA00 (START)
                                                ; STATEMENT # 67
                    ; PROCEDURE TIC_COUNT (START)
                                                ; STATEMENT # 68
0000      0500    F          INC    TEN_MSEC
                                                ; STATEMENT # 69
0002      D200    F          SETB   TAG_0_INTR3
                                                ; STATEMENT # 70
0004      E500    F          MOV    A,TEN_MSEC
0006      B4282A             CJNE   A,#28H,THEN?1
                                                ; STATEMENT # 72
0009      750000 F           MOV    TEN_MSEC,#00H
                                                ; STATEMENT # 73
000C      0500    F          INC    HUND_MSEC
                                                ; STATEMENT # 74
000E      D200    F          SETB   TAG_1_INTR3
                                                ; STATEMENT # 75
0010      E500    F          MOV    A,HUND_MSEC
0012      6421               XRL    A,#21H
0014      6005               JZ     BOOL?59
0016      E500    F          MOV    A,HUND_MSEC
0018      B44302             CJNE   A,#43H,THEN?2
001B              BOOL?59:
                                                ; STATEMENT # 76
001B      D200    F          SETB   TAG_2_INTR3
                                                ; STATEMENT # 77
001D              THEN?2:
001D      E500    F          MOV    A,HUND_MSEC
001F      B46411             CJNE   A,#64H,THEN?3
                                                ; STATEMENT # 79
0022      750000 F           MOV    HUND_MSEC,#00H
                                                ; STATEMENT # 80
```

```
0025     0500   F        INC    SEC
                                       ; STATEMENT # 81
0027     D200   F        SETB   TAG_3_INTR3
                                       ; STATEMENT # 82
0029     B200   F        CPL    BLINK
                                       ; STATEMENT # 83
002B     E500   F        MOV    A,SEC
002D     B40A03          CJNE   A,#0AH,THEN?4
                                       ; STATEMENT # 84
0030     750000 F        MOV    SEC,#00H
                                       ; STATEMENT # 85
0033             THEN?4:
                                       ; STATEMENT # 86
0033             THEN?3:
                                       ; STATEMENT # 87
0033             THEN?1:
0033     22              RET
                 ; PROCEDURE TIC_COUNT (END)
                                       ; STATEMENT # 88
                 ; PROCEDURE DAC_UPDATE (START)
                                       ; STATEMENT # 89
0034     A2B4            MOV    C,DAC_COMP
0036     9200   F        MOV    UP_DNNOT_FLAG,C
                                       ; STATEMENT # 90
0038     A200   F        MOV    C,UP_DNNOT_FLAG
003A     B3              CPL    C
003B     4026            JC     THEN?5
                                       ; STATEMENT # 92
003D     AE00   F        MOV    R6,DAC_COUNTER
003F     AF00   F        MOV    R7,DAC_COUNTER+0001H
0041     900000 F        MOV    DPTR,#DAC_MAX_COUNT
0044     E4              CLR    A
0045     93              MOVC   A,@A+DPTR
0046     FC              MOV    R4,A
0047     7401            MOV    A,#01H
0049     93              MOVC   A,@A+DPTR
004A     FD              MOV    R5,A
004B     EF              MOV    A,R7
004C     C3              CLR    C
004D     9D              SUBB   A,R5
004E     EE              MOV    A,R6
004F     9C              SUBB   A,R4
0050     400A            JC     THEN?6
                                       ; STATEMENT # 93
0052     900000 F        MOV    DPTR,#DAC_MAX_COUNT
0055     7800   F        MOV    R0,#DAC_COUNTER
0057     120000 F        LCALL  ?P0008
                                       ; STATEMENT # 94
005A     8005            SJMP   ELSE?7
005C             THEN?6:
005C     7800   F        MOV    R0,#DAC_COUNTER
005E     120000 F        LCALL  ?P0024
                                       ; STATEMENT # 95
0061             ELSE?7:
```

```
                                                ; STATEMENT # 96
0061      8013                    SJMP   ELSE?8
0063              THEN?5:
                                                ; STATEMENT # 97
0063      E500    F               MOV    A,DAC_COUNTER+0001H
0065      4500    F               ORL    A,DAC_COUNTER
0067      7008                    JNZ    THEN?9
                                                ; STATEMENT # 98
0069      750000 F                MOV    DAC_COUNTER+0001H,#00H
006C      750000 F                MOV    DAC_COUNTER,#00H
                                                ; STATEMENT # 99
006F      8005                    SJMP   ELSE?10
0071              THEN?9:
0071      7800    F               MOV    RO,#DAC_COUNTER
0073      120000 F                LCALL ?P0026
                                                ; STATEMENT # 100
0076              ELSE?10:
                                                ; STATEMENT # 101
0076              ELSE?8:
                                                ; STATEMENT # 102
0076      AE00    F               MOV    R6,DAC_COUNTER
0078      AF00    F               MOV    R7,DAC_COUNTER+0001H
007A      7404                    MOV    A,#04H
007C      120000 F                LCALL ?P0032
007F      8E00    F               MOV    TEMPOR_WORD,R6
0081      8F00    F               MOV    TEMPOR_WORD+0001H,R7
                                                ; STATEMENT # 103
0083      E500    F               MOV    A,TEMPOR_WORD
0085      F580                    MOV    PORT_0,A
                                                ; STATEMENT # 104
0087      E500    F               MOV    A,TEMPOR_WORD+0001H
0089      F500    F               MOV    TEMPOR_BIT_OVR,A
                                                ; STATEMENT # 105
008B      A200    F               MOV    C,TEMPOR_BIT.B7
008D      9293                    MOV    PORT_1_BIT_3,C
                                                ; STATEMENT # 106
008F      A200    F               MOV    C,TEMPOR_BIT.B6
0091      9292                    MOV    PORT_1_BIT_2,C
                                                ; STATEMENT # 107
0093      A200    F               MOV    C,TEMPOR_BIT.B5
0095      9291                    MOV    PORT_1_BIT_1,C
                                                ; STATEMENT # 108
0097      A200    F               MOV    C,TEMPOR_BIT.B4
0099      9290                    MOV    PORT_1_BIT_0,C
                                                ; STATEMENT # 110
009B      22                      RET
                  ; PROCEDURE DAC_UPDATE (END)
                                                ; STATEMENT # 111
                  ; PROCEDURE ANALYSIS (START)
                                                ; STATEMENT # 112
009C      E500    F               MOV    A,ZONE_I
009E      900000 F                MOV    DPTR,#CASE?JMPTBL?03BE
00A1      25E0                    ADD    A,ACC
00A3      73                      JMP    @A+DPTR
```

```
00A4                 CASE?98:
                                                  ; STATEMENT # 113
00A4      0100      F           AJMP   CASEND?11
00A6                 CASE?99:
                                                  ; STATEMENT # 115
00A6      A200      F           MOV    C,ZONE_1
00A8      4002                  JC     THEN?12
                                                  ; STATEMENT # 117
00AA      D200      F           SETB   ZONE_1
                                                  ; STATEMENT # 119
00AC                 THEN?12:
00AC      AE00      F           MOV    R6,DAC_COUNTER
00AE      AF00      F           MOV    R7,DAC_COUNTER+0001H
00B0      900000 F              MOV    DPTR,#PEAK_1
00B3      E4                    CLR    A
00B4      93                    MOVC   A,@A+DPTR
00B5      FC                    MOV    R4,A
00B6      7401                  MOV    A,#01H
00B8      93                    MOVC   A,@A+DPTR
00B9      FD                    MOV    R5,A
00BA      EF                    MOV    A,R7
00BB      D3                    SETB   C
00BC      9D                    SUBB   A,R5
00BD      EE                    MOV    A,R6
00BE      9C                    SUBB   A,R4
00BF      4002                  JC     THEN?13
                                                  ; STATEMENT # 120
00C1      D200      F           SETB   FAIL_ZONE_1
                                                  ; STATEMENT # 121
00C3                 THEN?13:
00C3      8074                  SJMP   CASEND?11
00C5                 CASE?100:
                                                  ; STATEMENT # 123
00C5      A200      F           MOV    C,ZONE_2
00C7      4004                  JC     THEN?14
                                                  ; STATEMENT # 125
00C9      C200      F           CLR    ZONE_1
                                                  ; STATEMENT # 126
00CB      D200      F           SETB   ZONE_2
                                                  ; STATEMENT # 128
00CD                 THEN?14:
00CD      AE00      F           MOV    R6,DAC_COUNTER
00CF      AF00      F           MOV    R7,DAC_COUNTER+0001H
00D1      900000 F              MOV    DPTR,#PEAK_2
00D4      E4                    CLR    A
00D5      93                    MOVC   A,@A+DPTR
00D6      FC                    MOV    R4,A
00D7      7401                  MOV    A,#01H
00D9      93                    MOVC   A,@A+DPTR
00DA      FD                    MOV    R5,A
00DB      EF                    MOV    A,R7
00DC      D3                    SETB   C
00DD      9D                    SUBB   A,R5
00DE      EE                    MOV    A,R6
```

```
00DF      9C                  SUBB   A,R4
00E0      4002                JC     THEN?15
                                              ; STATEMENT # 129
00E2      D200   F            SETB   PASS_ZONE_2
                                              ; STATEMENT # 130
00E4             THEN?15:
00E4      8053                SJMP   CASEND?11
00E6             CASE?101:
                                              ; STATEMENT # 132
00E6      A200   F            MOV    C,ZONE_3
00EB      400A                JC     THEN?16
                                              ; STATEMENT # 134
00EA      C200   F            CLR    ZONE_2
                                              ; STATEMENT # 135
00EC      D200   F            SETB   ZONE_3
                                              ; STATEMENT # 136
00EE      750000 F            MOV    PEAK_COUNTER+0001H,#00H
00F1      750000 F            MOV    PEAK_COUNTER,#00H
                                              ; STATEMENT # 138
00F4             THEN?16:
00F4      A200   F            MOV    C,UP_DNNOT_FLAG
00F6      B3                  CPL    C
00F7      4014                JC     THEN?17
                                              ; STATEMENT # 140
00F9      AE00   F            MOV    R6,PEAK_COUNTER
00FB      AF00   F            MOV    R7,PEAK_COUNTER+0001H
00FD      74FF                MOV    A,#0FFH
00FF      D3                  SETB   C
0100      9F                  SUBB   A,R7
0101      74FF                MOV    A,#0FFH
0103      9E                  SUBB   A,R6
0104      4005                JC     THEN?18
                                              ; STATEMENT # 141
0106      7800   F            MOV    R0#PEAK_COUNTER
0108      120000 F            LCALL  ?P0024
                                              ; STATEMENT # 142
010B             THEN?18:
                                              ; STATEMENT # 143
010B      800B                SJMP   ELSE?19
010D             THEN?17:
                                              ; STATEMENT # 144
010D      E500   F            MOV    A,PEAK_COUNTER+0001H
010F      4500   F            ORL    A,PEAK_COUNTER
0111      6005                JZ     THEN?20
                                              ; STATEMENT # 145
0113      7800   F            MOV    R0,#PEAK_COUNTER
0115      120000 F            LCALL  ?P0026
                                              ; STATEMENT # 146
0118             THEN?20:
                                              ; STATEMENT # 147
0118             ELSE?19:
0118      AE00   F            MOV    R6,PEAK_COUNTER
011A      AF00   F            MOV    R7,PEAK_COUNTER+0001H
011C      900000 F            MOV    DPTR,#PEAK_3
```

```
011F     E4                 CLR    A
0120     93                 MOVC   A,@A+DPTR
0121     FC                 MOV    R4,A
0122     7401               MOV    A,#01H
0124     93                 MOVC   A,@A+DPTR
0125     FD                 MOV    R5,A
0126     EF                 MOV    A,R7
0127     D3                 SETB   C
0128     9D                 SUBB   A,R5
0129     EE                 MOV    A,R6
012A     9C                 SUBB   A,R4
012B     4002               JC     THEN?21
                                          ; STATEMENT # 148
012D     D200    F          SETB   FAIL_ZONE_3
                                          ; STATEMENT # 149
012F             THEN?21:
012F     8008               SJMP   CASEND?11
0131             CASE?102:
                                          ; STATEMENT # 151
0131     A200    F          MOV    C,ZONE_4
0133     4004               JC     THEN?22
                                          ; STATEMENT # 153
0135     C200    F          CLR    ZONE_3
                                          ; STATEMENT # 154
0137     D200    F          SETB   ZONE_4
                                          ; STATEMENT # 156
0139             THEN?22:
                                          ; STATEMENT # 157
0139             CASEND?11:
                                          ; STATEMENT # 158
0139     22                 RET
                 ; PROCEDURE ANALYSIS (END)
                                          ; STATEMENT # 159
                 ; PROCEDURE SWITCH (START)
                                          ; STATEMENT # 160
013A     A2B3               MOV    C,START_STOP_SW
013C     9200    F          MOV    START_N,C
                                          ; STATEMENT # 161
013E     A200    F          MOV    C,START_N
0140     B3                 CPL    C
0141     B3                 CPL    C
0142     5005               JNC    BOOL?61
0144     A200    F          MOV    C,START_P
0146     B3                 CPL    C
0147     4002               JC     BOOL?63
0149             BOOL?61:
0149     8002               SJMP   THEN?23
014B             BOOL?63:
                                          ; STATEMENT # 162
014B     B200    F          CPL    START
                                          ; STATEMENT # 163
014D             THEN?23:
014D     A200    F          MOV    C,START_N
014F     9200    F          MOV    START_P,C
```

```
                                                ; STATEMENT # 164
0151     22                       RET
                     ; PROCEDURE SWITCH (END)
                                                ; STATEMENT # 165
                     ; PROCEDURE TIME (START)
                                                ; STATEMENT # 166
0152     A200    F                MOV     C,START
0154     400F                     JC      THEN?24
                                                ; STATEMENT # 168
0156     C200    F                CLR     RUN
                                                ; STATEMENT # 169
0158     C200    F                CLR     FINISH
                                                ; STATEMENT # 170
015A     C200    F                CLR     ZONE_1
                                                ; STATEMENT # 171
015C     C200    F                CLR     ZONE_2
                                                ; STATEMENT # 172
015E     C200    F                CLR     ZONE_3
                                                ; STATEMENT # 173
0160     C200    F                CLR     ZONE_4
                                                ; STATEMENT # 174
0162     750000  F                MOV     ZONE_I,#00H
                                                ; STATEMENT # 176
0165             THEN?24:
0165     A200    F                MOV     C,START
0167     B3                       CPL     C
0168     B3                       CPL     C
0169     500A                     JNC     BOOL?65
016B     A200    F                MOV     C,RUN
016D     B3                       CPL     C
016E     5005                     JNC     BOOL?67
0170     A200    F                MOV     C,FINISH
0172     B3                       CPL     C
0173     4002                     JC      BOOL?69
0175             BOOL?67:
0175             BOOL?65:
0175     800E                     SJMP    THEN?25
0177             BOOL?69:
                                                ; STATEMENT # 178
0177     C200    F                CLR     FAIL_ZONE_1
                                                ; STATEMENT # 179
0179     C200    F                CLR     PASS_ZONE_2
                                                ; STATEMENT # 180
017B     C200    F                CLR     FAIL_ZONE_3
                                                ; STATEMENT # 181
017D     750000  F                MOV     RUN_COUNTER+0001H,#00H
0180     750000  F                MOV     RUN_COUNTER,#00H
                                                ; STATEMENT # 182
0183     D200    F                SETB    RUN
                                                ; STATEMENT # 184
0185             THEN?25:
0185     A200    F                MOV     C,START
0187     B3                       CPL     C
0188     B3                       CPL     C
```

```
0189      500C               JNC    BOOL?71
018B      A200    F          MOV    C,RUN
018D      B3                 CPL    C
018E      B3                 CPL    C
018F      5006               JNC    BOOL?73
0191      A200    F          MOV    C,ZONE_4
0193      B3                 CPL    C
0194      B3                 CPL    C
0195      4002               JC     BOOL?75
0197                BOOL?73:
0197                BOOL?71:
0197      8004               SJMP THEN?26
0199                BOOL?75:
                                               ; STATEMENT # 186
0199      D200    F          SETB   FINISH
                                               ; STATEMENT # 187
019B      C200    F          CLR    RUN
                                               ; STATEMENT # 189
019D                THEN?26:
019D      22                 RET
                    ; PROCEDURE TIME (END)
                                               ; STATEMENT # 190
                    ; PROCEDURE LITE (START)
                                               ; STATEMENT # 191
019E      750006 F           MOV    WINDOW,#06H
                                               ; STATEMENT # 192
01A1      E500    F          MOV    A,DAC_COUNTER+0001H
01A3      4500    F          ORL    A,DAC_COUNTER
01A5      7002               JNZ    THEN?27
                                               ; STATEMENT # 193
01A7      1500    F          DEC    WINDOW
                                               ; STATEMENT # 194
01A9                THEN?27:
01A9      AE00    F          MOV    R6,DAC_COUNTER
01AB      AF00    F          MOV    R7,DAC_COUNTER+0001H
01AD      900000 F           MOV    DPTR,#WINDOW_1
01B0      E4                 CLR    A
01B1      93                 MOVC   A,@A+DPTR
01B2      FC                 MOV    R4,A
01B3      7401               MOV    A,#01H
01B5      93                 MOVC   A,@A+DPTR
01B6      FD                 MOV    R5,A
01B7      ED                 MOV    A,R5
01B8      D3                 SETB   C
01B9      9F                 SUBB   A,R7
01BA      EC                 MOV    A,R4
01BB      9E                 SUBB   A,R6
01BC      4002               JC     THEN?28
                                               ; STATEMENT # 195
01BE      1500    F          DEC    WINDOW
                                               ; STATEMENT # 196
01C0                THEN?28:
01C0      AE00    F          MOV    R6,DAC_COUNTER
01C2      AF00    F          MOV    R7,DAC_COUNTER+0001H
```

```
01C4     900000 F         MOV   DPTR,#WINDOW_2
01C7     E4               CLR   A
01C8     93               MOVC  A,@A+DPTR
01C9     FC               MOV   R4,A
01CA     7401             MOV   A,#01H
01CC     93               MOVC  A,@A+DPTR
01CD     FD               MOV   R5,A
01CE     ED               MOV   A,R5
01CF     D3               SETB  C
01D0     9F               SUBB  A,R7
01D1     EC               MOV   A,R4
01D2     9E               SUBB  A,R6
01D3     4002             JC    THEN?29
                                         ; STATEMENT # 197
01D5     1500   F         DEC   WINDOW
                                         ; STATEMENT # 198
01D7             THEN?29:
01D7     AE00   F         MOV   R6,DAC_COUNTER
01D9     AF00   F         MOV   R7,DAC_COUNTER+0001H
01DB     900000 F         MOV   DPTR,#WINDOW_3
01DE     E4               CLR   A
01DF     93               MOVC  A,@A+DPTR
01E0     FC               MOV   R4,A
01E1     7401             MOV   A,#01H
01E3     93               MOVC  A,@A+DPTR
01E4     FD               MOV   R5,A
01E5     ED               MOV   A,R5
01E6     D3               SETB  C
01E7     9F               SUBB  A,R7
01E8     EC               MOV   A,R4
01E9     9E               SUBB  A,R6
01EA     4002             JC    THEN?30
                                         ; STATEMENT # 199
01EC     1500   F         DEC   WINDOW
                                         ; STATEMENT # 200
01EE             THEN?30:
01EE     AE00   F         MOV   R6,DAC_COUNTER
01F0     AF00   F         MOV   R7,DAC_COUNTER+0001H
01F2     900000 F         MOV   DPTR,#WINDOW_4
01F5     E4               CLR   A
01F6     93               MOVC  A,@A+DPTR
01F7     FC               MOV   R4,A
01F8     7401             MOV   A,#01H
01FA     93               MOVC  A,@A+DPTR
01FB     FD               MOV   R5,A
01FC     ED               MOV   A,R5
01FD     D3               SETB  C
01FE     9F               SUBB  A,R7
01FF     EC               MOV   A,R4
0200     9E               SUBB  A,R6
0201     4002             JC    THEN?31
                                         ; STATEMENT # 201
0203     1500   F         DEC   WINDOW
                                         ; STATEMENT # 202
```

```
0205                 THEN?31:
0205      AE00   F           MOV    R6,DAC_COUNTER
0207      AF00   F           MOV    R7,DAC_COUNTER+0001H
0209      900000 F           MOV    DPTR,#WINDOW_5
020C      E4                 CLR    A
020D      93                 MOVC   A,@A+DPTR
020E      FC                 MOV    R4,A
020F      7401               MOV    A,#01H
0211      93                 MOVC   A,@A+DPTR
0212      FD                 MOV    R5,A
0213      ED                 MOV    A,R5
0214      D3                 SETB   C
0215      9F                 SUBB   A,R7
0216      EC                 MOV    A,R4
0217      9E                 SUBB   A,R6
0218      4002               JC     THEN?32
                                           ; STATEMENT # 203
021A      1500   F           DEC    WINDOW
                                           ; STATEMENT # 204
021C                 THEN?32:
021C      AE00   F           MOV    R6,DAC_COUNTER
021E      AF00   F           MOV    R7,DAC_COUNTER+0001H
0220      EF                 MOV    A,R7
0221      B4FF07             CJNE   A,#0FFH,THEN?33
0224      EE                 MOV    A,R6
0225      B40F03             CJNE   A,#0FH,THEN?33
                                           ; STATEMENT # 205
0228      850000 F           MOV    WINDOW,WINDOW
                                           ; STATEMENT # 206
022B                 THEN?33:
022B      E500   F           MOV    A,WINDOW
022D      900000 F           MOV    DPTR,#CASE?JMPTBL?03BE+000AH
0230      25E0               ADD    A,ACC
0232      73                 JMP    @A+DPTR
0233                 CASE?103:
                                           ; STATEMENT # 208
0233      A200   F           MOV    C,BLINK
0235      92A4               MOV    LO_RED_LED,C
                                           ; STATEMENT # 209
0237      C2A3               CLR    LO_YEL_LED
                                           ; STATEMENT # 210
0239      C2A2               CLR    ZERO_GRN_LED
                                           ; STATEMENT # 211
023B      C2A1               CLR    HI_YEL_LED
                                           ; STATEMENT # 212
023D      C2A0               CLR    HI_RED_LED
                                           ; STATEMENT # 213
023F      8048               SJMP   CASEND?34
0241                 CASE?104:
                                           ; STATEMENT # 215
0241      D2A4               SETB   LO_RED_LED
                                           ; STATEMENT # 216
0243      C2A3               CLR    LO_YEL_LED
                                           ; STATEMENT # 217
```

```
0245        C2A2                 CLR    ZERO_GRN_LED
                                               ; STATEMENT # 218
0247        C2A1                 CLR    HI_YEL_LED
                                               ; STATEMENT # 219
0249        C2A0                 CLR    HI_RED_LED
                                               ; STATEMENT # 220
024B        803C                 SJMP   CASEND?34
024D                  CASE?105:
                                               ; STATEMENT # 222
024D        C2A4                 CLR    LO_RED_LED
                                               ; STATEMENT # 223
024F        D2A3                 SETB   LO_YEL_LED
                                               ; STATEMENT # 224
0251        C2A2                 CLR    ZERO_GRN_LED
                                               ; STATEMENT # 225
0253        C2A1                 CLR    HI_YEL_LED
                                               ; STATEMENT # 226
0255        C2A0                 CLR    HI_RED_LED
                                               ; STATEMENT # 227
0257        8030                 SJMP   CASEND?34
0259                  CASE?106:
                                               ; STATEMENT # 229
0259        C2A4                 CLR    LO_RED_LED
                                               ; STATEMENT # 230
025B        C2A3                 CLR    LO_YEL_LED
                                               ; STATEMENT # 231
025D        D2A2                 SETB   ZERO_GRN_LED
                                               ; STATEMENT # 232
025F        C2A1                 CLR    HI_YEL_LED
                                               ; STATEMENT # 233
0261        C2A0                 CLR    HI_RED_LED
                                               ; STATEMENT # 234
0263        8024                 SJMP   CASEND?34
0265                  CASE?107:
                                               ; STATEMENT # 236
0265        C2A4                 CLR    LO_RED_LED
                                               ; STATEMENT # 237
0267        C2A3                 CLR    LO_YEL_LED
                                               ; STATEMENT # 238
0269        C2A2                 CLR    ZERO_GRN_LED
                                               ; STATEMENT # 239
026B        D2A1                 SETB   HI_YEL_LED
                                               ; STATEMENT # 240
026D        C2A0                 CLR    HI_RED_LED
                                               ; STATEMENT # 241
026F        8018                 SJMP   CASEND?34
0271                  CASE?108:
                                               ; STATEMENT # 243
0271        C2A4                 CLR    LO_RED_LED
                                               ; STATEMENT # 244
0273        C2A3                 CLR    LO_YEL_LED
                                               ; STATEMENT # 245
0275        C2A2                 CLR    ZERO_GRN_LED
                                               ; STATEMENT # 246
```

```
0277     C2A1               CLR    HI_YEL_LED
                                             ; STATEMENT # 247
0279     D2A0               CLR    HI_RED_LED
                                             ; STATEMENT # 248
027B     800C               SJMP   CASEND?34
027D           CASE?109:
                                             ; STATEMENT # 250
027D     C2A4               CLR    LO_RED_LED
                                             ; STATEMENT # 251
027F     C2A3               CLR    LO_YEL_LED
                                             ; STATEMENT # 252
0281     C2A2               CLR    ZERO_GRN_LED
                                             ; STATEMENT # 253
0283     C2A1               CLR    HI_YEL_LED
                                             ; STATEMENT # 254
0285     A200      F        MOV    C,BLINK
0287     92A0               MOV    HI_RED_LED,C
                                             ; STATEMENT # 256
0289           CASEND?34:
                                             ; STATEMENT # 257
0289     A200      F        MOV    C,START
028B     4002               JC     THEN?35
                                             ; STATEMENT # 258
028D     C2A7               CLR    RUN_LED
                                             ; STATEMENT # 259
028F            THEN?35:
028F     A200      F        MOV    C,RUN
0291     B3                 CPL    C
0292     B3                 CPL    C
0293     5006               JNC    BOOL?77
0295     A200      F        MOV    C,START
0297     B3                 CPL    C
0298     B3                 CPL    C
0299     4002               JC     BOOL?79
029B            BOOL?77
029B     8002               SJMP   THEN?36
029D            BOOL?79
                                             ; STATEMENT # 260
029D     D2A7               SETB   RUN_LED   ; STATEMENT # 261
029F            THEN?36:
029F     A200      F        MOV    C,FINISH
02A1     B3                 CPL    C
02A2     B3                 CPL    C
02A3     5006               JNC    BOOL?81
02A5     A200      F        MOV    C,START
02A7     B3                 CPL    C
02A8     B3                 CPL    C
02A9     4002               JC     BOOL?83
02AB            BOOL?81:
02AB     8004               SJMP   THEN?37
02AD            BOOL?83:
                                             ; STATEMENT # 262
02AD     A200      F        MOV    C,BLINK
```

```
02AF      92A7               MOV    RUN_LED,C
                                                ; STATEMENT # 263
02B1                THEN?37:
02B1      A200      F        MOV    C,START
02B3      4002               JC     THEN?38
                                                ; STATEMENT # 264
02B5      C2A5               CLR    FAIL_LED
                                                ; STATEMENT # 265
02B7                THEN?38:
02B7      A200      F        MOV    C,START
02B9      B3                 CPL    C
02BA      B3                 CPL    C
02BB      5005               JNC    BOOL?85
02BD      A200      F        MOV    C,FINISH
02BF      B3                 CPL    C
02C0      4002               JC     BOOL?87
02C2                BOOL?85
02C2      8006               SJMP   THEN?39
02C4                BOOL?87:
                                                ; STATEMENT # 266
02C4      A200      F        MOV    C,FAIL_ZONE_1
02C6      7200      F        ORL    C,FAIL_ZONE_3
02C8      92A5               MOV    FAIL_LED,C
                                                ; STATEMENT # 267
02CA                THEN?39:
02CA      A200      F        MOV    C,FINISH
02CC      B3                 CPL    C
02CD      4011               JC     THEN?40
                                                ; STATEMENT # 268
02CF      A200      F        MOV    C,FAIL_ZONE_1
02D1      7200      F        ORL    C,FAIL_ZONE_3
02D3      4005               JC     BOOL?89
02D5      A200      F        MOV    C,PASS_ZONE_2
02D7      B3                 CPL    C
02D8      5003               JNC    BOOL?91
02DA                BOOL?89:
02DA      D3                 SETB   C
02DB      8001               SJMP   BOOL?93
02DD                BOOL?91
02DD      C3                 CLR    C
02DE                BOOL?93:
02DE      92A5               MOV    FAIL_LED,C
                                                ; STATEMENT # 269
02E0                THEN?40:
02E0      A200      F        MOV    C,START
02E2      4002               JC     THEN?41
                                                ; STATEMENT # 270
02E4      C2A6               CLR    PASS_LED
                                                ; STATEMENT # 271
02E6                THEN?41:
02E6      A200      F        MOV    C,START
02E8      B3                 CPL    C
02E9      B3                 CPL    C
02EA      5005               JNC    BOOL?94
```

```
02EC      A200    F          MOV    C,FINISH
02EE      B3                 CPL    C
02EF      4002               JC     BOOL?96
02F1              BOOL?94:
02F1      8004               SJMP   THEN?42
02F3              BOOL?96:
                                          ; STATEMENT # 272
02F3      A200    F          MOV    C,PASS_ZONE_2
02F5      92A6               MOV    PASS_LED,C
                                          ; STATEMENT # 273
02F7              THEN?42:
02F7      A200    F          MOV    C,FINISH
02F9      B3                 CPL    C
02FA      4005               JC     THEN?43
                                          ; STATEMENT # 274
02FC      A2A5               MOV    C,FAIL_LED
02FE      B3                 CPL    C
02FF      92A6               MOV    PASS_LED,C
                                          ; STATEMENT # 275
0301              THEN?43:
0301      22                 RET
                  ; PROCEDURE LITE (END)
                                          ; STATEMENT # 276
                  ; PROCEDUERE ZONE (START)
                                          ; STATEMENT # 277
0302      A200    F          MOV    C,RUN
0304      B3                 CPL    C
0305      4065               JC     THEN?44
                                          ; STATEMENT # 279
0307      AE00    F          MOV    R6,RUN_COUNTER
0309      AF00    F          MOV    R7,RUN_COUNTER+0001H
030B      900000  F          MOV    DPTR,#TIME 4
030E      E4                 CLR    A
030F      93                 MOVC   A,@A+DPTR
0310      FC                 MOV    R4,A
0311      7401               MOV    A,#01H
0313      93                 MOVC   A,@A+DPTR
0314      FD                 MOV    R5,A
0315      ED                 MOV    A,R5
0316      D3                 SETB   C
0317      9F                 SUBB   A,R7
0318      EC                 MOV    A,R4
0319      9E                 SUBB   A,R6
031A      4003               JC     THEN?45
                                          ; STATEMENT # 280
031C      750004  F          MOV    ZONE_I,#04H
                                          ; STATEMENT # 281
031F              THEN?45:
031F      AE00    F          MOV    R6,RUN_COUNTER
0321      AF00    F          MOV    R7,RUN_COUNTER+0001H
0323      900000  F          MOV    DPTR,#TIME_3
0326      E4                 CLR    A
0327      93                 MOVR   A,@A+DPTR
0328      FC                 MOV    R4,A
```

```
0329    7401            MOV    A,#01H
032B    93              MOVC   A,@A+DPTR
032C    FD              MOV    R5,A
032D    ED              MOV    A,R5
032C    D3              SETB   C
032F    9F              SUBB   A,R7
0330    EC              MOV    A,R4
0331    9E              SUBB   A,R6
0332    4003            JC     THEN?46
                                       ; STATEMENT # 282
0334    750003 F        MOV    ZONE_I,#03H
                                       ; STATEMENT # 283
0337           THEN?46:
0337    AE00   F        MOV    R6,RUN_COUNTER
0339    AF00   F        MOV    R7,RUN_COUNTER+0001H
033B    900000 F        MOV    DPTR,#TIME_2
033E    E4              CLR    A
033F    93              MOVC   A,@A_DPTR
0340    FC              MOV    R4,A
0341    7401            MOV    A,#01H
0343    93              MOVC   A,@A+DPTR
0344    FD              MOV    R5,A
0345    ED              MOV    A,R5
0346    D3              SETB   C
0347    9F              SUBB   A,R7
0348    EC              MOV    A,R4
0349    9E              SUBB   A,R6
034A    4003            JC     THEN?47
                                       ; STATEMENT # 284
034C    750002 F        MOV    ZONE_I#02H
                                       ; STATEMENT # 285
034F           THEN?47
034F    AE00   F        MOV    R6,RUN_COUNTER
0351    AF00   F        MOV    R7,RUN_COUNTER+0001H
0353    900000 F        MOV    DPTR,#TIME_1
0356    E4              CLR    A
0357    93              MOVC   A,@A+DPTR
0358    FC              MOV    R4,A
0359    7401            MOV    A,#01H
035B    93              MOVC   A,@A+DPTR
035C    FD              MOV    R5,A
035D    ED              MOV    A,R5
035E    D3              SETB   C
035F    9F              SUBB   A,R7
0360    EC              MOV    A,R4
0361    9E              SUBB   A,R6
0362    4003            JC     THEN?48
                                       ; STATEMENT # 286
0364    750001 F        MOV    ZONE_I,#01H
                                       ; STATEMENT # 287
0367           THEN?48
0367    7800   F        MOV    RO,#RUN_COUNTER
0369    120000 F        LCALL  ?P0024
                                       ; STATEMENT # 289
```

```
036C                THEN?44:
036C      22                  RET
                    ; PROCEDURE ZONE (END)
                                        ; STATEMENT # 290
036D      75816F              MOV    SP,#6FH
                                        ; STATEMENT # 291
0370      758913              MOV    TMOD,#13H
                                        ; STATEMENT # 292
0373      758840              MOV    TCON,#40H
                                        ; STATEMENT # 293
0376      759800              MOV    SCON,#00H
                                        ; STATEMENT # 294
0379      75B81F              MOV    IP,#1FH
                                        ; STATEMENT # 295
037C      75A808              MOV    IE,#08H
                                        ; STATEMENT # 296
037F      D2AF                SETB   EA
                                        ; STATEMENT # 297
0381      C200    F           CLR    START
                                        ; STATEMENT # 298
0383      750000  F           MOV    ZONE_I,#00H
                                        ; STATEMENT # 299
0386      750000  F           MOV    DAC_COUNTER+0001H,#00H
0389      750000  F           MOV    DAC_COUNTER,#00H
                                        ; STATEMENT # 300
038C                WHILE?49:
                                        ; STATEMENT # 301
038C                WHILE?51:
038C      A200    F           MOV    C,TAG_0_INTR3
038E      B3                  CPL    C
038F      4008                JC     WEND?52
                                        ; STATEMENT # 302
0391      1100    F           ACALL  DAC_UPDATE
                                        ; STATEMENT # 303
0393      1100    F           ACALL  ANALYSIS
                                        ; STATEMENT # 304
0395      C200    F           CLR    TAG_0_INTR3
                                        ; STATEMENT # 305
0397      80F3                SJMP   WHILE?51
0399                WEND?52:
                                        ; STATEMENT # 306
0399                WHILE?53:
0399      A200    F           MOV    C,TAG_1_INTR3
039B      B3                  CPL    C
039C      4008                JC     WEND?54
                                        ; STATEMENT # 307
039E      1100    F           ACALL  SWITCH
                                        ; STATEMENT # 308
03A0      1100    F           ACALL  TIME
                                        ; STATEMENT # 309
03A2      C200    F           CLR    TAG_1_INTR3
                                        ; STATEMENT # 310
03A4      80F3                SJMP   WHILE?53
03A6                WEND?54
```

```
                                                        ; STATEMENT # 311
03A6                    WHILE?55:
03A6        A200    F           MOV     C,TAG_2_INTR3
03A8        B3                  CPL     C
03A9        4006                JC      WEND?56
                                                        ; STATEMENT # 312
03AB        1100    F           ACALL   LITE
                                                        ; STATEMENT # 313
03AD        C200    F           CLR     TAG_2_INTR3
                                                        ; STATEMENT # 314
03AF        80F5                SJMP    WHILE?55
03B1                    WEND?56:
                                                        ; STATEMENT # 315
03B1                    WHILE?57:
03B1        A200    F           MOV     C,TAG_3_INTR3
03B3        B3                  CPL     C
03B4        4006                JC      WEND?58
                                                        ; STATEMENT # 316
03B6        1100    F           ACALL   ZONE
                                                        ; STATEMENT # 317
03B8        C200    F           CLR     TAG_3_INTR3
                                                        ; STATEMENT # 318
03BA        80F5                SJMP    WHILE?57
03BC                    WEND?58:
                                                        ; STATEMENT # 319
03BC        80CE                SJMP    WHILE?49
03BE                    WEND?50:
                                                        ; STATEMENT # 320
                        ; PROCEDURE NASA00 (END)
03BE                    CASE?JMPTBL?03BE:
                                                        ; JUMP TABLE FOR DO CASE
                                                          LEVEL 1
03BE        0100    F           AJMP    CASE?98
03C0        0100    F           AJMP    CASE?99
03C2        0100    F           AJMP    CASE?100
03C4        0100    F           AJMP    CASE?101
03C6        0100    F           AJMP    CASE?102
03C8        0100    F           AJMP    CASE?103
03CA        0100    F           AJMP    CASE?104
03CC        0100    F           AJMP    CASE?105
03CE        0100    F           AJMP    CASE?106
03D0        0100    F           AJMP    CASE?107
03D2        0100    F           AJMP    CASE?108
03D4        0100    F           AJMP    CASE?109
```

CROSS-REFERENCE LISTING

```
DEFN  SPACE  SIZE  NAME                   ATTRIBUTES AND REFERENCES

 111  CODE    158  ANALYSIS. . . . PROCEDURE USING(0) STACK=02H
                                             303
  65     BIT    1            B0. . . . . . . . BIT MEMBER OF TEMPOR_BIT ;
                                                 OFFSET=0
  65     BIT    1            B1. . . . . . . . BIT MEMBER OF TEMPOR_BIT ;
                                                 OFFSET=1
  65     BIT    1            B2. . . . . . . . BIT MEMBER OF TEMPOR_BIT ;
                                                 OFFSET=2
  65     BIT    1            B3. . . . . . . . BIT MEMBER OF TEMPOR_BIT ;
                                                 OFFSET=3
  65     BIT    1            B4. . . . . . . . BIT MEMBER OF TEMPOR_BIT ;
                                                 OFFSET=4 108
  65     BIT    1            B5. . . . . . . . BIT MEMBER OF TEMPOR_BIT ;
                                                 OFFSET=5 107
  65     BIT    1            B6. . . . . . . . BIT MEMBER OF TEMPOR_BIT ;
                                                 OFFSET=6 106
  65     BIT    1            B7. . . . . . . . BIT MEMBER OF TEMPOR_BIT ;
                                                 OFFSET=7 105
  52     BIT    1            BLINK . . . . . . BIT
                                               82  208  254  262
  24                         DAC_COMP. . . . . BIT REGISTER AT(B4H)
                                               89
  25     DATA   2            DAC_COUNTER . . . WORD
                                               92   93   94   97   98   99 102
                                              119  128  192  194  196  198 200
                                              202  204  299
  29     CODE   2            DAC_MAX_COUNT . . WORD
                                               92   93
  88     CODE   104          DAC_UPDATE. . . . PROCEDURE USING(0) STACK=02H
                                              302
   2                         DCL . . . . . . . LITERALLY
                                                2    3    4    5    6    7    8
                                                9   10   11   12   13   14   15
                                               16   17   18   19   20   21   22
                                               23   24   25   26   27   28   29
                                               30   31   32   33   34   35   36
                                               37   38   39   40   41   42   43
                                               44   45   46   47   48   49   50
                                               51   52   53   54   55   56   57
                                               58   59   60   61   62   63   64
                                               65
  22                         EA. . . . . . . . BIT REGISTER AT(AFH)
                                              296
  19                         FAIL_LED. . . . . BIT REGISTER AT(A5H)
                                              264  266  268  274
  62     BIT    1            FAIL_ZONE_1 . . . BIT
                                              120  178  266  268
  64     BIT    1            FAIL_ZONE_3 . . . BIT
```

```
                                             148 180 266 268
 57     BIT     1     FINISH. . . . . BIT
                                             169 176 186 261 265 267 271
                                             273
                      HIGH. . . . . . BUILTIN
                                             103
 14                   HI_RED_LED. . . BIT REGISTER AT(A0H)
                                             212 219 226 233 240 247 254
 15                   HI_YEL_LED. . . BIT REGISTER AT(A1H)
                                             211 218 225 232 239 246 253
 43     DATA    1     HUND_MSEC . . . BYTE
                                              73  75  77  79
  8                   IE. . . . . . . BYTE REGISTER AT(A8H)
                                             295
  9                   IP. . . . . . . BYTE REGISTER AT(B8H)
                                             294
190     CODE  356     LITE. . . . . . PROCEDURE USING(0) STACK=02H
                                             312
                      LOW . . . . . . BUILTIN
                                             104
 18                   LO_RED_LED. . . BIT REGISTER AT(A4H)
                                             208 215 222 229 236 243 250
 17                   LO_YEL_LED. . . BIT REGISTER AT(A3H)
                                             209 216 223 230 237 244 251
  1     CODE   81     NASA00. . . . . MODULE
 20                   PASS_LED. . . . BIT REGISTER AT(A6H)
                                             270 272 274
 63     BIT     1     PASS_ZONE_2 . . BIT
                                             129 179 268 272
 30     CODE    2     PEAK_1. . . . . WORD
                                             119
 31     CODE    2     PEAK_2. . . . . WORD
                                             128
 32     CODE    2     PEAK_3. . . . . WORD
                                             147
 26     DATA    2     PEAK_COUNTER. . WORD
                                             136 140 141 144 145 147
  3                   PORT_0. . . . . BYTE REGISTER AT(80H)
                                             103
 10                   PORT_1_BIT_0. . BIT REGISTER AT(90H)
                                             108
 11                   PORT_1_BIT_1. . BIT REGISTER AT(91H)
                                             107
 12                   PORT_1_BIT_2. . BIT REGISTER AT(92H)
                                             106
 13                   PORT_1_BIT_3. . BIT REGISTER AT(93H)
                                             105
 56     BIT     1     RUN . . . . . . BIT
                                             168 176 182 184 187 259 277
 27     DATA    2     RUN_COUNTER . . WORD
                                             181 279 281 283 285 287
 21                   RUN_LED . . . . BIT REGISTER AT(A7H)
                                             258 260 262
  7                   SCON. . . . . . BYTE REGISTER AT(98H)
```

```
                                                   293
   44      DATA    1          SEC . . . . . . . BYTE
                                                    80   83   84
                              SHL . . . . . . . BUILTIN
                                                   102
    4                         SP. . . . . . . . BYTE REGISTER AT(81H)
                                                   290
   53      BIT     1          START . . . . . . BIT
                                                   162 166 176 184 257 259 261
                                                   263 265 269 271 297
   54      BIT     1          START_N . . . . . BIT
                                                   160 161 163
   55      BIT     1          START_P . . . . . BIT
                                                   161 163
   23                         START_STOP_SW . . BIT REGISTER AT(B3H)
                                                   160
  159      CODE    24         SWITCH. . . . . . PROCEDURE USING(0) STACK=02H
                                                   307
   48      BIT     1          TAG_0_INTR3 . . . BIT
                                                    69 301 304
   49      BIT     1          TAG-1-INTR3 . . . BIT
                                                    74 306 309
   50      BIT     1          TAG_2_INTR3 . . . BIT
                                                    76 311 313
   51      BIT     1          TAG_3_INTR3 . . . BIT
                                                    81 315 317
    5                         TCON. . . . . . . BYTE REGISTER AT(88H)
                                                  292
   65      BITAD   1          TEMPOR_BIT. . . . STRUCTURE
                                                   66 105 106 107 108
   66      DATA    1          TEMPOR_BIT_OVR. . BYTE AT(.TEMPOR_BIT)
                                                  104
   28      DATA    2          TEMPOR_WORD . . . WORD
                                                  102 103 104
   42      DATA    1          TEN_MSEC. . . . . BYTE
                                                   68   70   72
   67      CODE    52         TIC_COUNT . . . . PROCEDURE USING(0) STACK=09H
                                                      INTERRUPT(3)
  165      CODE    76         TIME. . . . . . . PROCEDURE USING(0) STACK=02H
                                                  308
   38      CODE    2          TIME_1. . . . . . WORD
                                                  285
   39      CODE    2          TIME_2. . . . . . WORD
                                                  283
   40      CODE    2          TIME_3. . . . . . WORD
                                                  281
   41      CODE    2          TIME_4. . . . . . WORD
                                                  279
    6                         TMOD. . . . . . . BYTE REGISTER AT(89H)
                                                  291
   47      BIT     1          UP_DNNOT_FLAG . . BIT
                                                   89   90 138
   45      DATA    1          WINDOW. . . . . . BYTE
                                                  191 193 195 197 199 201 203
```

```
                                                       205 206
   33       CODE     2          WINDOW_1. . . . WORD
                                                       194
   34       CODE     2          WINDOW_2. . . . WORD
                                                       196
   35       CODE     2          WINDOW_3. . . . WORD
                                                       198
   36       CODE     2          WINDOW_4. . . . WORD
                                                       200
   37       CODE     2          WINDOW_5. . . . WORD
                                                       202
   16                           ZERO_GRN_LED. . BIT REGISTER AT(A2H)
                                                210 217 224 231 238 245 252
  276       CODE     107        ZONE. . . . . . PROCEDURE USING(0) STACK=02H
                                                316
   58       BIT      1          ZONE_1. . . . . BIT
                                                115   117   125   170
   59       BIT      1          ZONE_2. . . . . BIT
                                                123   126   134   171
   60       BIT      1          ZONE_3. . . . . BIT
                                                132   135   153   172
   61       BIT      1          ZONE_4. . . . . BIT
                                                151   154   173   184
   46       DATA     1          ZONE_I. . . . . BYTE
                                                112   174   280   282
                                                284   286   298


WARNINGS:
    3 IS HIGHEST USED INTERRUPT


MODULE INFORMATION:                      (STATIC+OVERLAYABLE)
    CODE SIZE                            = 03D6H         982D
    CONSTANT SIZE                        = 001AH          26D
    DIRECT VARIABLE SIZE                 =   0DH+00H      13D+   0D
    INDIRECT VARIABLE SIZE               =   00H+00H       0D+   0D
    BIT SIZE                             =   12H+00H      18D+   0D
    BIT-ADDRESSABLE SIZE                 =   01H+00H       1D+   0D
    AUXILIARY VARIABLE SIZE              = 0000H           0D
    MAXIMUM STACK SIZE                   = 0011H          17D
    REGISTER-BANK(S) USED:               =0
    409 LINES READ
    0 PROGRAM ERROR(S)
END OF PL/M-51 COMPLIATION
```

```
ISIS-II MCS-51 RELOCATOR AND LINKER, V3.0,INVOKED BY:
 RL51 :F0:NASA00.OBJ,:F0:PLM51.LIB TO NASA00.ABS PRINT(:LP:)

INPUT MODULES INCLUDED
   :F0:NASA00.OBJ(NASA00)
   :F0:PLM51.LIB(?P0008)
   :F0:PLM51.LIB(?P0024)
   :F0:PLM51.LIB(?P0026)
   :F0:PLM51.LIB(?P0032)
   :F0:PLM51.LIB(?PIV03)
   :F0:PLM51.LIB(?PIVOR)
   :F0:PLM51.LIB(?PIP03)

LINK MAP FOR :F0:NASA00.ABS(NASA00)


   TYPE    BASE      LENGTH      RELOCATION     SEGMENT NAME
   ----    ----      ------      ----------     ------------

   REG     0000H     0008H                      "REG BANK 0"
   DATA    0008H     000DH       UNIT           ?NASA00?DT
           0015H     000BH                      *** GAP ***
   DATA    0020H     0001H       BIT_ADDR       ?NASA00?BA
   BIT     0021H     0002H.2     UNIT           ?NASA00?BI
           0023H.2   0000H.6                    *** GAP ***
   IDATA   0024H     0001H       UNIT           ?STACK


   CODE    0000H     0003H       ABSOLUTE
   CODE    0003H     000EH       UNIT           ?P0032S
   CODE    0011H     0009H       UNIT           ?P0008S
           001AH     0001H                      *** GAP ***
   CODE    001BH     0003H       ABSOLUTE
   CODE    001EH     03D6H       INBLOCK        ?NASA00?PR
   CODE    03F4H     001BH       UNIT           ?PIP03S
   CODE    040FH     001AH       UNIT           ?NASA00?CO
   CODE    0429H     0009H       UNIT           ?PIVORS
   CODE    0432H     0008H       UNIT           ?P0024S
   CODE    043AH     0008H       UNIT           ?P0026S


SYMBOL TABLE FOR :F0:NASA00.ABS(NASA00)


VALUE     TYPE      NAME
-----     ----      ----

-------   MODULE    NASA00
C:038BH   SYMBOL    NASA00
D:0080H   SYMBOL    PORT_0
D:0081H   SYMBOL    SP
D:0088H   SYMBOL    TCON
D:0089H   SYMBOL    TMOD
D:0098H   SYMBOL    SCON
```

```
D:00A8H    SYMBOL   IE
D:00B8H    SYMBOL   IP
B:0090H    SYMBOL   PORT_1_BIT_0
B:0090H.1  SYMBOL   PORT_1_BIT_1
B:0090H.2  SYMBOL   PORT_1_BIT_2
B:0090H.3  SYMBOL   PORT_1_BIT_3
B:00A0H    SYMBOL   HI_RED_LED
B:00A0H.1  SYMBOL   HI_YEL_LED
B:00A0H.2  SYMBOL   ZERO_GRN_LED
B:00A0H.3  SYMBOL   LO_YEL_LED
B:00A0H.4  SYMBOL   LO_RED_LED
B:00A0H.5  SYMBOL   FAIL_LED
B:00A0H.6  SYMBOL   PASS_LED
B:00A0H.7  SYMBOL   RUN_LED
B:00A8H.7  SYMBOL   EA
B:00B0H.3  SYMBOL   START_STOP_SW
B:00B0H.4  SYMBOL   DAC_COMP
D:0008H    SYMBOL   DAC_COUNTER
D:000AH    SYMBOL   PEAK_COUNTER
D:000CH    SYMBOL   RUN_COUNTER
D:000EH    SYMBOL   TEMPOR_WORD
C:040FH    SYMBOL   DAC_MAX_COUNT
C:0411H    SYMBOL   PEAK_1
C:0413H    SYMBOL   PEAK_2
C:0415H    SYMBOL   PEAK_3
C:0417H    SYMBOL   WINDOW_1
C:0419H    SYMBOL   WINDOW_2
C:041BH    SYMBOL   WINDOW_3
C:041DH    SYMBOL   WINDOW_4
C:041FH    SYMBOL   WINDOW_5
C:0421H    SYMBOL   TIME_1
C:0423H    SYMBOL   TIME_2
C:0425H    SYMBOL   TIME_3
C:0427H    SYMBOL   TIME_4
D:0010H    SYMBOL   TEN_MSEC
D:0011H    SYMBOL   HUND_MSEC
D:0012H    SYMBOL   SEC
D:0013H    SYMBOL   WINDOW
D:0014H    SYMBOL   ZONE_I
B:0021H    SYMBOL   UP_DNNOT_FLAG
B:0021H.1  SYMBOL   TAG_0_INTR3
B:0021H.2  SYMBOL   TAG_1_INTR3
B:0021H.3  SYMBOL   TAG_2_INTR3
B:0021H.4  SYMBOL   TAG_3_INTR3
B:0021H.5  SYMBOL   BLINK
B:0021H.6  SYMBOL   START
B:0021H.7  SYMBOL   START_N
B:0022H    SYMBOL   START_P
B:0022H.1  SYMBOL   RUN
B:0022H.2  SYMBOL   FINISH
B:0022H.3  SYMBOL   ZONE_1
B:0022H.4  SYMBOL   ZONE_2
B:0022H.5  SYMBOL   ZONE_3
B:0022H.6  SYMBOL   ZONE_4
```

```
B:0022H.7 SYMBOL   FAIL_ZONE_1
B:0023H   SYMBOL   PASS_ZONE_2
B:0023H.1 SYMBOL   FAIL_ZONE_3
D:0020H   SYMBOL   TEMPOR_BIT
D:0020H   SYMBOL   TEMPOR_BIT_OVR
C:001EH   SYMBOL   TIC_COUNT
-------   PROC     TIC_COUNT
-------   ENDPROC  TIC_COUNT
C:0052H   SYMBOL   DAC_UPDATE
-------   PROC     DAC_UPDATE
-------   ENDPROC  DAC_UPDATE
C:00BAH   SYMBOL   ANALYSIS
-------   PROC     ANALYSIS
-------   ENDPROC  ANALYSIS
C:0158H   SYMBOL   SWITCH
-------   PROC     SWITCH
-------   ENDPROC  SWITCH
C:0170H   SYMBOL   TIME
-------   PROC     TIME
-------   ENDPROC  TIME
C:01BCH   SYMBOL   LITE
-------   PROC     LITE
-------   ENDPROC  LITE
C:0320H   SYMBOL   ZONE
-------   PROC     ZONE
-------   ENDPROC  ZONE
C:038BH   LINE#    1
C:001EH   LINE#    67
C:001EH   LINE#    68
C:0020H   LINE#    69
C:0022H   LINE#    70
C:0027H   LINE#    72
C:002AH   LINE#    73
C:002CH   LINE#    74
C:002EH   LINE#    75
C:0039H   LINE#    76
C:003BH   LINE#    77
C:0040H   LINE#    79
C:0043H   LINE#    80
C:0045H   LINE#    81
C:0047H   LINE#    82
C:0049H   LINE#    83
C:004EH   LINE#    84
C:0051H   LINE#    85
C:0051H   LINE#    86
C:0051H   LINE#    87
C:0052H   LINE#    88
C:0052H   LINE#    89
C:0056H   LINE#    90
C:005BH   LINE#    92
C:0070H   LINE#    93
C:0078H   LINE#    94
C:007FH   LINE#    95
C:007FH   LINE#    96
```

C:0081H	LINE#	97
C:0087H	LINE#	98
C:008DH	LINE#	99
C:0094H	LINE#	100
C:0094H	LINE#	101
C:0094H	LINE#	102
C:00A1H	LINE#	103
C:00A5H	LINE#	104
C:00A9H	LINE#	105
C:00ADH	LINE#	106
C:00B1H	LINE#	107
C:00B5H	LINE#	108
C:00B9H	LINE#	110
C:00BAH	LINE#	111
C:00BAH	LINE#	112
C:00C2H	LINE#	113
C:00C4H	LINE#	115
C:00C8H	LINE#	117
C:00CAH	LINE#	119
C:00DFH	LINE#	120
C:00E1H	LINE#	121
C:00E3H	LINE#	123
C:00E7H	LINE#	125
C:00E9H	LINE#	126
C:00EBH	LINE#	128
C:0100H	LINE#	129
C:0102H	LINE#	130
C:0104H	LINE#	132
C:0108H	LINE#	134
C:010AH	LINE#	135
C:010CH	LINE#	136
C:0112H	LINE#	138
C:0117H	LINE#	140
C:0124H	LINE#	141
C:0129H	LINE#	142
C:0129H	LINE#	143
C:012BH	LINE#	144
C:0131H	LINE#	145
C:0136H	LINE#	146
C:0136H	LINE#	147
C:014BH	LINE#	148
C:014DH	LINE#	149
C:014FH	LINE#	151
C:0153H	LINE#	153
C:0155H	LINE#	154
C:0157H	LINE#	156
C:0157H	LINE#	157
C:0157H	LINE#	158
C:0158H	LINE#	159
C:0158H	LINE#	160
C:015CH	LINE#	161
C:0169H	LINE#	162
C:016BH	LINE#	163
C:016FH	LINE#	164

C:0170H	LINE#	165
C:0170H	LINE#	166
C:0174H	LINE#	168
C:0176H	LINE#	169
C:0178H	LINE#	170
C:017AH	LINE#	171
C:017CH	LINE#	172
C:017EH	LINE#	173
C:0180H	LINE#	174
C:0183H	LINE#	176
C:0195H	LINE#	178
C:0197H	LINE#	179
C:0199H	LINE#	180
C:019BH	LINE#	181
C:01A1H	LINE#	182
C:01A3H	LINE#	184
C:01B7H	LINE#	186
C:01B9H	LINE#	187
C:01BBH	LINE#	189
C:01BCH	LINE#	190
C:01BCH	LINE#	191
C:01BFH	LINE#	192
C:01C5H	LINE#	193
C:01C7H	LINE#	194
C:01DCH	LINE#	195
C:01DEH	LINE#	196
C:01F3H	LINE#	197
C:01F5H	LINE#	198
C:020AH	LINE#	199
C:020CH	LINE#	200
C:0221H	LINE#	201
C:0223H	LINE#	202
C:0238H	LINE#	203
C:023AH	LINE#	204
C:0246H	LINE#	205
C:0249H	LINE#	206
C:0251H	LINE#	208
C:0255H	LINE#	209
C:0257H	LINE#	210
C:0259H	LINE#	211
C:025BH	LINE#	212
C:025DH	LINE#	213
C:025FH	LINE#	215
C:0261H	LINE#	216
C:0263H	LINE#	217
C:0265H	LINE#	218
C:0267H	LINE#	219
C:0269H	LINE#	220
C:026BH	LINE#	222
C:026DH	LINE#	223
C:026FH	LINE#	224
C:0271H	LINE#	225
C:0273H	LINE#	226
C:0275H	LINE#	227

C:0277H	LINE#	229
C:0279H	LINE#	230
C:027BH	LINE#	231
C:027DH	LINE#	232
C:027FH	LINE#	233
C:0281H	LINE#	234
C:0283H	LINE#	236
C:0285H	LINE#	237
C:0287H	LINE#	238
C:0289H	LINE#	239
C:028BH	LINE#	240
C:028DH	LINE#	241
C:028FH	LINE#	243
C:0291H	LINE#	244
C:0293H	LINE#	245
C:0295H	LINE#	246
C:0297H	LINE#	247
C:0299H	LINE#	248
C:029BH	LINE#	250
C:029DH	LINE#	251
C:029FH	LINE#	252
C:02A1H	LINE#	253
C:02A3H	LINE#	254
C:02A7H	LINE#	256
C:02A7H	LINE#	257
C:02ABH	LINE#	258
C:02ADH	LINE#	259
C:02BBH	LINE#	260
C:02BDH	LINE#	261
C:02CBH	LINE#	262
C:02CFH	LINE#	263
C:02D3H	LINE#	264
C:02D5H	LINE#	265
C:02E2H	LINE#	266
C:02EBH	LINE#	267
C:02EDH	LINE#	268
C:02FEH	LINE#	269
C:0302H	LINE#	270
C:0304H	LINE#	271
C:0311H	LINE#	272
C:0315H	LINE#	273
C:031AH	LINE#	274
C:031FH	LINE#	275
C:0320H	LINE#	276
C:0320H	LINE#	277
C:0325H	LINE#	279
C:033AH	LINE#	280
C:033DH	LINE#	281
C:0352H	LINE#	282
C:0355H	LINE#	283
C:036AH	LINE#	284
C:036DH	LINE#	285
C:0382H	LINE#	286
C:0385H	LINE#	287

C:038AH	LINE#	289
C:038BH	LINE#	290
C:038EH	LINE#	291
C:0391H	LINE#	292
C:0394H	LINE#	293
C:0397H	LINE#	294
C:039AH	LINE#	295
C:039DH	LINE#	296
C:039FH	LINE#	297
C:03A1H	LINE#	298
C:03A4H	LINE#	299
C:03AAH	LINE#	300
C:03AAH	LINE#	301
C:03AFH	LINE#	302
C:03B1H	LINE#	303
C:03B3H	LINE#	304
C:03B5H	LINE#	305
C:03B7H	LINE#	306
C:03BCH	LINE#	307
C:03BEH	LINE#	308
C:03C0H	LINE#	309
C:03C2H	LINE#	310
C:03C4H	LINE#	311
C:03C9H	LINE#	312
C:03CBH	LINE#	313
C:03CDH	LINE#	314
C:03CFH	LINE#	315
C:03D4H	LINE#	316
C:03D6H	LINE#	317
C:03D8H	LINE#	318
C:03DAH	LINE#	319
C:03DCH	LINE#	320
-------	ENDMOD	NASA00

APPENDIX III

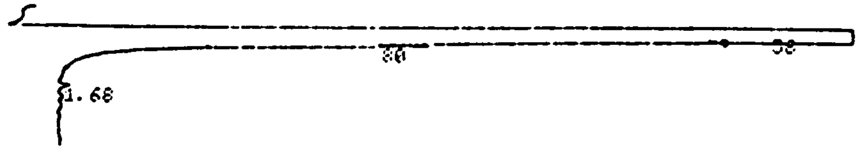
INSTRUMENT CONDITIONS

GOW-MAC INSTRUMENT CO.
BRIDGEWATER, NEW JERSEY
DATE

INSTR. MODEL	69-550	SAMPLE	JP-5 IN AVGAS
DETECTOR	TCD	SOLVENT	AVGAS
COLUMN SIZE	10'X1/8' SS	SAMPLE SIZE	1 MICROLITER
LIQUID PHASE		TEMP:	
SUPPORT		COLUMN	250 DEG.C
CARRIER GAS	HELIUM	INJ. PORT	250 DEG.C
CARRIER FLOW	30ml/MIN	DETECTOR	300 DEG.C
H2 FLOW		BRIDGE CURRENT	
AIR FLOW		ATTENUATION	1
RECORDER	FS:1mv	CHART SPEED	1cm/MIN

APPENDIX IV

CHANNEL A INJECT 10/14/85 13:08:11



10/14/85 13:08:11 CH= "A" PS= 1.

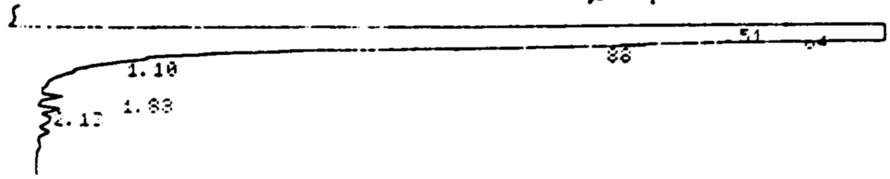
FILE 1. METHOD 0. RUN 5 INDEX 5

PEAK#	AREA%	RT	AREA BC
1	81.968	0.46	2678492 02
2	17.885	0.58	584419 02
3	0.146	0.8	4757 03
4	0.002	1.68	63 01
TOTAL	100.		3267731

0% JET FUEL; "PASS" LED ON

5.0

CHANNEL A INJECT 10/18/85 14:30:58 1% 1ul FAIL



10/18/85 14:30:58 CH= "A" PS= 1.

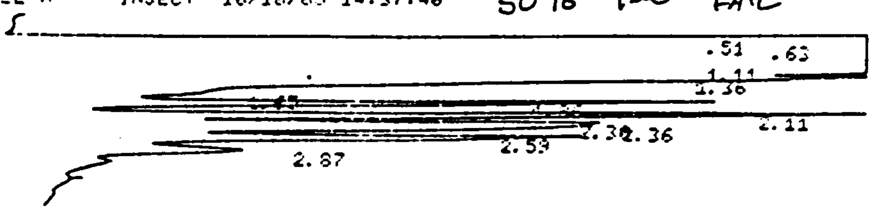
FILE 1. METHOD 0. RUN 3 INDEX 3

PEAK#	AREA%	RT	AREA BC
1	81.927	0.51	2999017 02
2	18.05	0.64	660739 08
3	0.012	0.86	451 05
4	0.001	1.1	31 05
5	0.006	1.86	206 01
6	0.004	2.13	161 01
TOTAL	100.		3660605

1% JET FUEL; "FAIL" LED ON

APPENDIX IV Sample Tests

CHANNEL A INJECT 10/18/85 14:37:40 50% 1ul FAIL



10/18/85 14:37:40 CH= "A" PS= 1.

FILE METHOD 0. RUN 4 INDEX 4

PEAK#	AREA%	RT	AREA BC
1	40.846	0.51	1553958 02
2	57.959	0.63	2205014 08
3	0.058	1.11	2202 05
4	0.062	1.36	2373 05
5	0.002	1.65	80 05
6	0.169	1.86	6413 05
7	0.248	2.11	9417 06
8	0.154	2.3	5853 06
9	0.188	2.36	7162 06
10	0.208	2.59	7906 06
11	0.106	2.87	4029 07
TOTAL	100.		3804407

50% JET FUEL; "FAIL" LED ON

NASA National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TP-2803		

4. Title and Subtitle	5. Report Date
Investigation of the Misfueling of Reciprocating Piston Aircraft Engines	March 1988
	6. Performing Organization Code: 824.2
7. Author(s): J. Holland Scott, Jr.	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address: NASA Goddard Space Flight Center, Wallops Flight Facility, Wallops Island, VA 23337	11. Contract or Grant No.
	13. Type of Report and Period Covered: Technical Paper
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Aircraft Misfueling Detection Project was developed by the Goddard Space Flight Center/Wallops Flight Facility at Wallops Island, Virginia. Its purpose was to investigate the misfueling of reciprocating piston aircraft engines by the inadvertent introduction of jet fuel in lieu of or as a contaminant of aviation gasoline (avgas). The final objective was the development of a device(s) that will satisfactorily detect misfueling and provide pilots with sufficient warning to avoid injury, fatality, or equipment damage. Two devices have been developed and successfully tested: one, a small contamination detection kit, for use by the pilot, and a second, more sensitive, modified gas chromatograph for use by the fixed-base operator (FBO). The gas chromatograph, in addition to providing excellent quality control of the FBO's fuel handling operation, is a very good back-up for the detection kit in the event it produces positive results. Design parameters were developed to the extent that they may be easily applied to commercial production by the aircraft industry.

17. Key Words (Suggested by Author(s))		18. Distribution Statement
General Aviation Aircraft	Jet Fuel	Unclassified - unlimited
Aircraft Engines	Detonation	
Misfueling	Evaporation	
Avgas	Detonable Gas Mixtures	
	Gas Chromatograph	Subject Category 03

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	79	A05